University of Alberta

Effects of Body Weight and Age at Photostimulation on Reproductive Efficiency in Meat-Type Hens (*Gallus domesticus*)

by

Paul Reginald Goerzen

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Effects of Body Weight and Age at Photostimulation on Reproductive Efficiency in Meat-Type Hens (*Gallus Domesticus)*** submitted by Paul Reginald Goerzen in partial fulfilment of the requirements for the degree of Master of Science in Animal Science.

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ABSTRACT

Three experiments were conducted in order to evaluate the effect of; 1) *ad-libitum* feeding on the duration of fertility, 2) time of weighing on pullet body weight (BW), and 3) differences in growth curve and age at photostimulation on carcass traits, ovarian morphology, and reproductive performance.

Feed restricted and *ad-libitum* fed broiler breeder hens were artificially inseminated twice on two consecutive days. The duration of fertility was impaired after *ad-libitum* feeding for 8 wk (*ad-libitum* fed =10.0 d, feed restricted =12.7 d). This study was the first to examine the effect of *ad-libitum* feeding on the duration of fertility. It serves to further characterize some of the causes of the negative effect of BW on reproductive efficiency.

The effect of time of weighing on observed mean BW in three pens consisting of 157 10-wk old broiler breeder pullets on a skip-a-day feed restriction program was determined for each of three 2-d replicates. It was determined that weekly BW measurements taken at different times (AM or PM, feed day or non-feed day) were not comparable and did not give an accurate representation of actual BW. It was shown that daily pullet growth is not linear and fluctuates significantly within and between days.

In the third experiment, 348 broiler breeder pullets were grown on the growth curves STANDARD, LOW (150 g lighter than STANDARD) and HIGH (150 g heavier than STANDARD), and photostimulated at either 19 wk of age (19WK) or 21 wk of age (21WK). At photostimulation, the HIGH birds were larger framed and had more carcass fat (7.2 %) than the LOW birds (6.0 %). At sexual maturity, the HIGH birds had a higher percent of large yellow follicles (LYF) within 1 g (48.2 %) than the STANDARD birds (29.5 %) and the LOW birds (22.8 %) that was associated with an increased production of double yolked eggs by the HIGH birds in the laying cycle. Heavier weight birds also showed mild symptoms of erratic ovulation and defective egg syndrome (EODES). Birds photostimulated earlier took longer to lay their first egg after photostimulation (19WK = 41.7 d, 21WK = 32.2 d). However, they laid their first settable egg at the same chronological age. Birds laying more total eggs and longer prime sequences had more LYF at 61 wk of age and were lower in BW than birds laying fewer total eggs and shorter prime sequence lengths. Between the differences in BW used here; 1) there was no advantage of early photostimulation, and 2) reproductive function of modern broiler breeders was shown to be negatively affected by moderate increases in BW.

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1. INTRODUCTION

1.1 BACKGROUND

1.1.1 Introduction

The modern broiler breeder female is a genetic compromise between two very different selection criteria. She must both possess the genetic ability grow rapidly and to be an efficient producer of hatching eggs. Reproductive problems introduced through 40 years of genetic selection for desirable meat production characteristics in the progeny have severely impaired the reproductive ability of the broiler parents (Siegel and Dunnington, 1985). Managers of broiler breeder flocks are faced with the challenge of ensuring the reproductive performance of a bird selected partially for meat production traits. Primary breeding companies are continually updating their management guides in order to improve the reproductive performance of their meat-type parents.

Over the last twenty years, feed restriction programs have become standard in order to limit body weight (BW) gains in an effort to maintain reproductive performance of broiler breeder hens. *Ad-libitum* fed egg-type hens are one half the BW of feed restricted broiler breeder hens (Anonymous, 1992; Anonymous, 1994d). This comparison exemplifies the negative relationship between BW and reproductive potential. Modern egg-type stocks routinely lay 300 eggs compared to modern broiler breeder hens who may produce 160 hatching eggs to the same age. A strong negative correlation between selection for growth and reproductive fitness in the chicken (Maloney *et al.*, 1967) has been recognized for 30 years.

Since the female parent is selected partially for meat production traits, genetically based gains in broiler growth rate are associated with an increased need for broiler breeder feed restriction. Current broiler breeder feed restriction programs limit BW to approximately one half the BW of a full fed bird at the time of photostimulation (Yu *et al.*, 1992b). Potential performance of a typical broiler breeder hen and broiler (Shaver Starbro) is shown in Table 1-1. In this case, genetic progress and intensive management, along with advances in nutrition, have developed a broiler breeder and a broiler with marked improvements

in performance.

1.1.2 State of the Meat-Type Breeder Industry

With advances in nutrition, disease control, housing, and transportation, in less than 50 years the chicken breeder industry has evolved from backyard seasonal production of replacement stock to a highly intensive industry dominated by a small number of companies worldwide. Primary chicken breeders are faced with the challenge of producing a competitive broiler while maintaining the reproductive potential of the female parent. It wasn't until the late 1940's that poultry breeding began to develop into a business as opposed to a hobby or sideline (Hunton, 1990). The large multinational conglomerate-owned breeding companies of today have developed by a process of expansion and take over (Hunton, 1990). In spite of this decline in the number of primary breeders, the consumption of chicken meat and the concurrent annual production of broiler breeders has increased dramatically. Canadian chicken production and per capita consumption of chicken has more than doubled in the last twenty years (Anonymous, 1995b). Similar trends have occurred in the United States in the same period of time (Aho, 1996). The genetic stock of modern meat-type chickens is under the control of an increasingly small number of companies.

There are four separate levels of production hierarchy that go into producing a broiler chicken; purelines, great grandparents, grandparents, and parents (Hunton, 1990). As seen in Figure 1-1, broiler chicks are the product of a terminal cross between the hybridized male of the male lines and the hybridized female of the female lines. Male lines are primarily based on the Cornish breed and female lines are based on the White Rock breed.

The chicken breeder industry has successfully developed a meat-type bird with the ability to grow to market weight within a shorter period of time than earlier stocks. Modern broilers grow at three times the rate of a 1957 random bred strain of broilers on a modern feeding program (Havenstein *et al.*, 1994). In fact, over the past 40 years primary breeders have been able to select for a broiler chicken that will grow to the same market weight in one day less each year (Gyles, 1989). However, this genetic gain has come at a cost. In Canada, ascites and sudden death syndrome account for 30% of the total mortality. Representing just as much cost to the industry are skeletal disorders such as tibial dyschondroplasia, chondrodystrophy,

spondylolisthesis and femoral head necrosis (Leeson *et al.*, 1995). These metabolic disorders can be reduced if not eliminated by accepting growth rates of less than genetic potential (Leeson *et al.*, 1995). Like her progeny, the broiler breeder hen has a reduced level of fitness due to this intensive selection pressure. Erratic ovulations, defective eggs, and poor egg production have characterised the reproductive performance of the broiler breeder hen for the last 25 years (Jaap and Muir, 1968; Yu *et al.*, 1992b; Robinson *et al.*, 1993b).

1.1.3 Recent Trends

In the short term, primary breeders are probably not going to sacrifice broiler growth performance to improve broiler breeder reproductive performance. Competition between primary breeders is severe and losses in market share due to reduced broiler growth rate would result (Hunton, 1990). Thus, detailed management has become a powerful tool to achieve satisfactory hatching egg production. Past and present broiler breeder management guides from Arbor-Acres Farms (Anonymous, 1980, 1985, 1989a, 1991a, 1994a, 1995a), Avian Farms International (Anonymous, 1991b, 1996a, 1996b), Hubbard Farms (Anonymous, 1976, 1989b, 1994b, 1994c) and Shaver Poultry Breeding Farms (Anonymous, 1970, 1979, 1983, 1986, 1989c, 1993b, 1994d) were reviewed. All of these primary breeders include BW targets for their birds. Weekly BW targets given in the form of a range were averaged by week and plotted against age for each of the different management guides (Figures 1-2 to 1-8). Only "in season" BW targets were used for this comparison. "In season" flocks are those flocks maturing under conditions of naturally increasing day length. "Season" is an important consideration under conditions of non-black out housing. "Out of season" BW targets for flocks maturing under conditions of naturally decreasing day length, are typically higher in order to encourage sexual development in decreasing day length environments. There is a high degree of variability in BW target recommendations between the primary breeders. Inspite of this variability, Shaver Poultry Breeding Farms, Arbor Acres Farms and Hubbard Farms have all reduced their target BW in their most recent management guide after a series of BW target increases (Figures 1-2 to 1-7). The Avian Farms International guide (Figure 1-8) also tells an important story. The Avian 34 is a fast feathering female breeder and the Avian 43 is a feather sexable female breeder. Avian Farms International

has developed a BW control program specific to each type of bird. Feed restriction programs are becoming increasingly fine tuned. Based on review of the fore-referenced breeder guides, recommended age at photostimulation has been delayed from 18 to 19 wk of age to at least 20 wk of age over the last decade. The effects of these trends are not well documented in the literature.

1.2 AVIAN REPRODUCTIVE PHYSIOLOGY

1.2.1 Introduction

Growth, sexual maturation, follicular development, and egg production are all partly regulated by the endocrinological events occurring in the hypothalamic-anterior pituitary-ovarian axis. Gonadotropin releasing hormone (GnRH) (Sharp, 1993), luteinizing hormone (LH) (Wilson and Cunningham, 1980), follicle stimulating hormone (FSH) (Palmer and Bahr, 1992), progesterone (Etches, 1990), estradiol (Robinson and Etches, 1986), and androstenedione (Robinson and Etches, 1986) are some of the reproductive hormones produced by the hypothalamic-anterior pituitary-ovarian axis. While understanding the factors affecting their release is essential to understanding reproductive physiology of the hen, growth and reproductive performance are the result of the interaction between genetic, nutritional and environmental factors with this endocrinological axis.

1.2.2 Growth Effects on Sexual Maturation

The broiler breeder female will grow rapidly to a very large BW under *ad-libitum* feeding conditions. At sexual maturity broiler breeder hens can easily reach 5 kg, which is well above the restricted BW target of 2.2 kg (Robinson *et al.*, 1991b; Yu *et al.*, 1992a). Current feed restriction programs attempt to limit BW, follicular development, and fat deposition to levels required for onset of lay and persistence of lay without becoming so great as to impair reproductive ability. The relationship between growth, genetics, nutrition, sexual maturation, and egg production is somewhat of a conundrum in the broiler breeder hen. Regardless of feeding program, the transition from pullet to hen appears to require the attainment of specific physiological thresholds before it will occur. Soller *et al.* (1984) pointed out that

among cattle, pigs, rats, mice, fish and humans, female undernourishment delays sexual maturity until about the same BW is attained as that of a comparable group of well fed animals at sexual maturity. Sexual maturation in chickens likely depends on the attainment of some or all of the following thresholds; body weight and chronological age (Brody *et al.*, 1980; Dunnington *et al.*, 1984), lean body mass (Soller *et al.*, 1984) and body fat (Bornstein *et al.*, 1984).

Lilburn and Myers-Miller (1990) showed that higher protein (22.7 vs 15.4% CP) and lower energy (2885 vs 3133 ME kcal/kg) levels fed between 13 and 18 wk of age did not effect BW yet increased *pectoralis major* weight while decreasing abdominal fat weight. At 25 wk of age there was no effect of protein or energy level during the rearing period on carcass traits. This would suggest a critical age beyond which carcass development would only be minimally affected by protein and energy intake. In spite of a proposed threshold BW, it has been shown that extreme levels of feed restriction will result in a lower BW at sexual maturity possibly due to impaired skeletal growth (Brody *et al.*, 1980; Leeson and Summers, 1984; Fattori *et al.*, 1993). Fattori *et al.* (1993) investigated the effect of small differences in BW target created by allocated feeds such that all treatments received equivalent amounts of all required nutrients except energy. They found a dose response of reduced days to sexual maturity (defined as age at 50% production) with increasing BW. After recording the abdominal fatpad weight, plasma lipid concentration, ovary weight and oviduct weight at 2 wk intervals from 22 to 28 wk of age, they concluded that feed restriction delayed the development of attributes associated with sexual maturity without altering their physiological values. This suggests that whereas the growth of the abdominal fatpad, ovary, and oviduct and the increase in plasma lipid delayed the onset of sexual maturity, after sexual maturity they were all the same. Wilson *et al.* (1995) took this even further by reporting that the significant effect of feed allocation on carcass traits at 25 wk were not significant at end of lay. Comparison of three different growth rates all converging to a common BW at 24 wk of age showed birds grown on a convex (early slow) rearing curve to have significantly less carcass protein and ash and numerically less carcass fat at 25 wk than birds grown on a linear or a concave (early fast) growth curve. Clearly, rate of growth and carcass composition before sexual maturity can be influenced by diet composition and allocation. Robinson and Robinson (1991) also found that the differences in carcass composition at sexual maturity of hens differing

in BW at 21 wk of age were not significant at end of lay. The low weight birds that were 1539 g at 21 wk laid their first egg later (199.3 d) than the high weight birds (183.7 d) who were 2446 g at 21 wk of age. Differences in BW observed at 21 wk of age persisted to 62 wk of age. Yet, after sexual maturity the influence of rearing treatments were no longer apparent in terms of carcass traits. Yu *et al.* (1992a) showed that at 18 wk of age, full fed pullets had 27.4% carcass fat compared to 7.3 % in their restricted counterparts. Carcass protein content was the same for both treatments (13.6%). On an absolute basis, the full fed birds had approximately ten times the fat content and twice the protein reserves of the restricted birds, due in part to a large BW difference. Similar trends were observed at sexual maturity. Threshold carcass traits for the onset of sexual maturity are sensitive to pre-breeding feed allocation and photostimulatory treatment. However, some time after sexual maturity, pre-breeding treatments are no longer apparent.

Feed restriction has a profound effect on the age at sexual maturity in broiler breeder hens. Sexual maturity is typically delayed in birds reared under conditions of feed restriction rather than *ad-libitum* feeding respectively; 190 to 165 d (Pym and Dillon, 1974), 190 to 174 d (Robbins *et al.*, 1986) and 174 to 157 d (Yu *et al.*, 1992b). Currently used levels of feed restriction induce only a minor delay in onset of sexual maturity when birds are photostimulated at 18 to 20 wk of age (Robinson *et al.*, 1993b). This delay is likely due to the delayed maturation of the hypothalamic-anterior pituitary axis (Yu *et al.*, 1992b). Attainment of sexual maturity may depend more heavily on a critical age in full fed meat-type breeders and more heavily on BW and carcass traits in feed restricted meat-type breeders (Katanbaf *et al.*, 1989). This makes intuitive sense given that there appears to be a threshold age and BW (Brody *et al.*, 1980) necessary for the onset of lay.

Full fed meat-type pullets will begin to show signs of ovarian follicular development at 14 wk of age in the absence of a photostimulatory cue (Hocking *et al.*, 1989). A positive relationship between BW and number of yellow follicles exists in meat-type females restricted after 14 wk of age (Hocking *et al.*, 1989). More large yellow follicles at sexual maturity disrupts normal ovarian function (Yu *et al.*, 1992b), and one additional large yellow follicle (LYF) at sexual maturity has been associated with a ten egg reduction in total egg production to 64 wk of age (Robinson *et al.*, 1995). It is very important to realize the

relationship between growth, sexual maturity and ovarian morphology when determining pre-breeding feed allocation for broiler breeders.

Photoperiodic control is an important tool used to control age at sexual maturity in an effort to maximize egg production. The targeted age at sexual maturity for egg-type birds is 21 to 22 wk of age (Anonymous, 1992) while that of meat-type birds is 26 to 27 wk of age (Anonymous, 1994d). Under conditions of continuous light (8L:16D), modern Single Combe White Leghorns (SCWL) will commence egg laying at 22 to 23 wk of age whereas feed restricted broiler breeder hens will begin laying at 29 to 30 wk of age (Lupicki, 1994). Recent work at the University of Alberta has shown that broiler breeders maintained on short days will lay their first egg at 28 wk of age whereas broiler breeders photostimulated at 20 wk will lay their first egg at 26 wk of age (Muller *et al.*, 1996). Of avian species, only the White-crowned sparrow (Follett *et al.*, 1975) and the Willow ptarmigan (Stokkan and Sharp, 1980) have been reported to fail initiation of reproductive function while exposed to continuous short days.

1.2.3 Maturation of Follicles

The ovary of a hen consists of about half a million oocytes, of which only 2000 are visible to the naked eye (Pearl and Schoppe, 1921). Follicles have been described as small white follicles (SWF), large white follicles (LWF), small yellow follicles (SYF) and large yellow follicles (LYF) (Robinson and Etches, 1986). Large yellow follicles are defined differently by different authors. Hocking and Hocking *et al.* (all years) define LYF as yolky follicles greater than 8 mm in diameter whereas Robinson *et al.* (all years) and Yu *et al.* (all years) define LYF as large yolky follicles greater than 10 mm in diameter. There may be from 4 to 12 LYF in the ovary of a laying broiler breeder hen depending on age and feeding program (Yu *et al.*, 1992b). The largest LYF is designated as the F1, the second largest as the F2 and so on. A follicle's ability to ovulate is not determined by its size but rather by it's ability to produce progesterone in response to LH (Etches *et al.*, 1983). While size is not be the best indication of the maturity or functionality of a LYF, it is the measure commonly used. During the 7 to 9 d prior to ovulation, yolk is rapidly deposited into the developing follicles (Warren and Conrad, 1939). During ovulation, the F1 follicle ruptures along the stigma, which consists primarily of collagenous tissue and lacks the connective tissue coat found in the

remainder of the follicle (Van Krey, 1990). The collagenous fibres are oriented parallel to the long axis of the stigma, making separation easier during ovulation.

Follicles of the ovary are the single cell oocyte which will give rise to the ovum or female gamete. This massive cell represents about 30% of the weight of the egg. The size of this cell, or yolk, are believed to have a direct influence on the size of the shelled egg (Romanoff and Romanoff, 1949). Estradiol stimulates the production of vitellogenin by the liver (Griffin *et al.*, 1984). Vitellogenin is transported to the ovary and deposited in the oocytes by receptor mediated endocytosis (Etches, 1996). As it enters the developing ovum, it is cleaved into phosvitin and lipovitellin. The yolk consists of the phosphoproteins phosvitin, lipovitellin and vitellogenin, triglyceride-rich lipoproteins, and water-soluble proteins. All of these plasma proteins are synthesized in the liver and their concentration in the plasma increases sharply in response to estrogen (Griffin *et al.*, 1984).

In the absence of a photostimulatory cue, during the first 14 to 15 wk of life the ovary of the domestic egg type hen grows slowly and only contains follicles less than 3 mm (Etches, 1990). At this point the ovary consists primarily of 0.06 to 0.08 mm follicles, small white follicles (SWF), and possibly some large white follicles (LWF). This pool of white follicles contains aromatase (Armstrong, 1984) which is involved in the production of large amounts of estrogen (Robinson and Etches, 1986) by as early as 15 wk of age (Peterson and Webster, 1974). At photostimulation, the basal plasma LH concentration increases from 1.5 ng/ml to 6 ng/ml (Wilson and Cunningham, 1980), which in turn accelerates ovarian growth and estrogen output (Robinson and Etches, 1986).

The major difference between the SWF and LYF is their content of yolk and the transformation of the multiple layers of granulosa cells in the immature follicle to a monolayer in the LYF (Etches, 1990). The mechanisms controlling the transfer of follicles into the SYF pool and onto the LYF hierarchy are not well understood. In contrast to earlier reports (Williams and Sharp, 1978b), the ovary of the laying hen contains a highly variable number of LYF depending on her age (Palmer and Bahr, 1992), feed allowance for meat-type hens (Hocking *et al.*, 1987; 1989; Hocking, 1993; Robinson *et al.*, 1995) and breed (Wautier, 1994). There are even marked differences in LYF numbers between different strains of meat-type hens at sexual maturity and at the end of lay (Wautier, 1994: Shaver Starbro; Yu *et al.*, 1992b: Indian River). The

transformation of a follicle from the white follicle pool into the yolky filled follicle pool is limited to a 10 h period of the ovulatory cycle (Zakaria *et al.*, 1984). However, these data were for egg-type hens and the recruitment characteristics may be different for meat-type hens.

Atresia is the process by which a SYF or LYF regress and the yolk is reabsorbed by the vascularization of the ovary. While shown to be a rare occurrence among the yolky follicles of egg-type hens unless induced by disease or starvation (Gilbert *et al.*, 1981, 1983; Waddington *et al*, 1985), atresia occurs more frequently among the yolky follicles of over fed meat-type hens (Hocking *et al.*, 1987, 1989). The processes underlying the selection criteria of a yellow follicle for atresia are not understood. Atresia among SYF, along with follicular growth and recruitment, may be one of the controlling mechanisms regulating ovulation (Gilbert *et al.*, 1983). When there are too many ovulable LYF on the ovary, atresia, along with multiple ovulation and internal ovulation, may occur. Internal ovulation occurs when the infundibulum does not capture the ovulated follicle. These processes reduce the number of follicles in the yolky hierarchy to a number suitable for normal ovulatory patterns, but can have undesirable effects. Multiple yolked eggs are not considered settable for chick production and internal ovulation can lead to peritonitis in the hen.

1.2.4 Follicular Function

Gonadotropin releasing hormone (GnRH) secretion from the hypothalamus, gonadotropin secretion from the anterior pituitary, and progesterone produced by the F1 follicle act in concert to control ovulation and follicular function. The mature F1 follicle produces progesterone which acts as a positive feedback through the hypothalamus to stimulate the release of additional GnRH (Etches, 1990). The mammalian gonadotropins LH and FSH are similar to glycoproteins found in chicken pituitary gland extracts (Godden and Scanes, 1975). For this reason the mammalian nomenclature has been adopted. As in mammals, FSH is believed to be responsible for follicular recruitment and growth (Mitchell, 1970; Masuda *et al.*, 1984; Palmer and Bahr, 1992). Unlike the mammalian LH, the avian LH-like glycoprotein does not luteinize but rather promotes steroidogenesis and stimulates ovulation (Etches, 1990). Luteinizing hormone concentrations in the plasma peak 4 to 6 h prior to ovulation, descend during the ovulatory period

and are maintained at peak levels in mid-ovulatory cycle (Etches and Cheng, 1981). During the the time known as the "open period for LH release" the hypothalamus is able to respond to progesterone production by the F1 follicle by secreting GnRH (Etches, 1990). This in turn will stimulate the release of a surge of LH from the anterior pituitary that is experienced by all follicles. Only the most mature follicle(s) would be able to respond to this LH surge by producing more progesterone, thus propagating the positive feedback through the hypothalamic-anterior pituitary axis (Johnson *et al.*, 1985). In response to the LH surge, the F1 follicle will ovulate along the stigma, leaving the post ovulatory follicle (POF). The ovarian follicle is composed of layers of tissue surrounding the oocyte or yolk. These layers include the plasma membrane, the perivitelline membrane, granulosa cells, basal lamina, theca interna, and theca externa.

There are two forms of chicken GnRH; cGnRH-I and cGnRH-II. Although they only differ in positions 5, 7 and 8 (Miyamoto *et al.*, 1982), only cGnRH-I is believed to be responsible for stimulating the release of gonadotropins from the anterior pituitary gland (Sharp *et al.*, 1990). Sharp *et al.* (1990) showed that the concentration of cGnRH-II in the hypothalamus did not change in response to puberty. In addition, immunization against cGnRH-II did not result in a reduction in plasma LH and ovarian regression, unlike with immunization against cGnRH-I.

Progesterone is produced by the granulosa cells of the large yellow follicles (Etches and Duke, 1984). The secreted progesterone is used by the theca cells of the same follicle to metabolize androgens and estrogen (Huang *et al.*, 1979). The small follicles cannot utilize progesterone as a substrate for androstenedione production so they must use the **Δ**-5 pathway to metabolize pregnenolone to androstenedione throughout the intermediates 17-**α**-OH-pregnenolone and dehydroepiandrosterone (Robinson and Etches, 1986). Androstenedione is a precursor to estradiol. After incorporation into the large yellow follicular hierarchy, the F2 - Fn LYF theca cells can only produce androstenedione via the **Δ**-4 pathway through the intermediates progesterone and 17-**α**-OH-progesterone (Robinson and Etches, 1986). The amount of progesterone in the granulosa cells of the LYF increases as the follicle progresses through the hierarchy (Etches and Duke, 1984). While all of the LYF produce progesterone, it is only released by the F1 which unlike the other LFY in the hierarchy, does not have theca cells able to convert progesterone to androstenedione (Robinson and Etches, 1986). Only the F1 granulosa cell releases progesterone into the

systemic circulation, as the adjacent theca cells have lost the ability to convert progesterone to androstenedione.

The ability of LYF theca cells to produce estrogens decreases as follicles move through the hierarchy, with the F1 having no estrogen production capabilities (Robinson and Etches, 1986). Estrogens do not play a major role in regulation of the ovulatory cycle (Etches, 1990). They are, however, involved in sensitization of the hypothalamic-pituitary axis to progesterone (Wilson and Sharp, 1976). Estrogens have more general effects of stimulating vitellogenesis (Redshaw and Follett., 1972), deposition of Ca in the medullary bone of the long bones (Etches, 1987), stimulation and maintenance of oviductal function, and development of secondary sexual characteristics such as comb, wattles and feather development (Johnson, 1986).

Prostaglandins of the F series are found in the wall of the F1 follicle and are produced in large amounts, 100 fold more than that of the F1, in the post ovulatory follicle (POF) 24 h after it's own ovulation (Day and Nalbandov, 1977). Shimada *et al.* (1983) also concluded that the POF synthesizes prostaglandins, releases it into the blood and stimulates uterine (shell gland) contractions. Considering the proximity of the prostaglandin peak to subsequent ovulation, it has been tempting to assign it a regulatory role. However, it does not appear to play a role in the ovulatory cycle of the hen (Day and Nalbandov, 1977). Considering the known action of the prostaglandins, prostaglandin E causeing relaxation of the vaginal sphincter and prostaglandin F stimulating smooth muscle, it is generally accepted that they are involved in facilitating oviposition of the egg (Etches, 1996).

1.2.5 Egg Formation

Birds normally have one left functional reproductive tract, known as the oviduct. The right oviduct is a nonfunctional vestige attached to the cloaca (Somes *et al.*, 1990). Under abnormal circumstances the right oviduct may become enlarged and fill with fluid (Somes *et al.*, 1990). McBride (1962) classified incidence of right oviductal development as; 1) right and left ovaries and oviducts fully developed, 2) right oviduct development and some gonadal development on the right side, 3) right and left oviductal development but complete absence of right gonad, and 4) one oviduct and ovary normal with an

imperfect (normally cystic) right oviduct. The latter two represent most of the reported cases (Somes *et al.*, 1990). Recently a hen with two fully developed oviducts was found at the University of Alberta as one of 64 hens killed at sexual maturity in a lighting trial (Muller *et al.*, 1996). The oviduct is one continuous seven layer tube that is divided into five regions; infundibulum, magnum, isthmus, shell gland and vagina. It is a very motile organ and the muscular tissues of the tract are supplied with neural inputs from the autonomic nervous system. The form and function of the oviduct have been reviewed by Solomon (1983), Johnson (1986), Proudman (1995) and Etches (1996).

The infundibulum is funnel shaped and thin walled. It envelopes the ovum within about 20 minutes of ovulation and is the site of fertilization. The infundibular region also has some capacity for sperm storage. After copulation or artificial insemination (AI), sperm is stored in and slowly released from a network of invaginations of the surface epithelium lining of the uterovaginal junction called sperm storage tubules (Proudman, 1995). These tubules can store and release viable sperm for up to 3 to 4 wk in the chicken and for up to 8 to 15 wk in the turkey (Brillard, 1993). Sperm travel up the oviduct to the site of fertilization in the infundibulum where there is a second set of sperm storage tubules. The infundibulum is about 9 cm long and the ovum resides in this region for about 0.25 h.

The magnum is the largest region of the oviduct at 33 cm long. Over 3 h thick albumen is formed and deposited around the ovum. As the developing egg passes through the magnum, the egg distends the secretory cells located within ridges of the magnum wall, initiating discharge of the formed egg white proteins (Etches, 1996). The peristaltic movements of the magnum are induced by it's moderate musculature.

The beginning of the isthmus is marked by a translucent border. The inner and outer shell membranes are formed during the 1.5 h that the ovum spends in the 10 cm isthmus. The ridges of the isthmus are aligned longitudinally, not spirally as in the magnum. The inner and outer shell membranes are formed by the intermeshing of fibres that are secreted by the tubular glands (Etches, 1996). The tubular glands lie parallel to the egg surface and are surrounded by a glycoprotein mantle secreted by the secretory cells of the epithelium (Etches, 1996). The fibres of the outer shell membrane are thicker, in spite of the fact that they are apparently secreted from the same cell.

The shell gland, sometimes inappropriately called the uterus, is thick and muscular. The egg spends 18 to 22 h in the shell gland. The shell gland has both ciliated nonsecretory epithelial cells and non-ciliated secretory epithelial cells arranged in the small folds of the mucosa (Johnson, 1986). The shell gland serves to plump the shelless egg with approximately 15 g water, add salts (Na^+, K^+ and Cl^-), deposit the $CaCO_3$ shell, pigment (if any), and the glycoprotein cuticle. In the vagina, the egg turns pointed end caudal to blunt end caudal just prior to oviposition.

1.2.6 Problems with Egg Formation

In a set of classical studies, Jaap and Muir (1968) and van Middelkoop (1971, 1972) characterized the condition know as erratic ovulation defective egg syndrome (EODES) in which meat-type parents laid eggs with a high proportion of improperly shelled or double yolked eggs. They concluded that this was the result of different ovulations occurring within the same period often in an erratic nature throughout the solar day. Multiple ovulations occurring within the same period often result in two developing eggs being in the oviduct at once. Often the result is two improperly shelled eggs, one normal egg and one soft shelled egg, or one double yolked egg. Poorly shelled eggs reduce embryo survivability and double yolked eggs are not considered settable. Recent work at the University of Alberta has characterised EODES and it's relationship to body weight in SCWLs (Bjerstedt *et al.*, 1995), broiler breeders (Yu *et al.*, 1992b, 1992c; Robinson *et al.*,1995) and turkeys (Renema *et al.*, 1995). Bjerstedt *et al.* (1995) sorted 62 wk old SCWL hens into BW groups. They found that a quarter of the heavier BW hens had some incidence of internal ovulation whereas lower BW groups had no incidence of internal ovulation. Yu *et al.* (1992b, 1992c) and Robinson *et al.* (1995) have reported that *ad-libitum* feeding and reduced levels of feed restriction in the pre-breeding period have a negative effect on the production of settable eggs, a result of excess follicular development in the ovary leading to a lack of ovarian control. Using male line turkey hens, Renema *et al.* (1995) reported that feed restriction reduced the number of multiple follicular sets leading to an increased level of ovarian control evidenced by longer egg laying sequences and shorter pause lengths between sequences.

1.2.7 Light Perception

The breeding season of birds and many wild mammals is controlled by both photoperiodic and nonphotoperiodic factors (Wingfield *et al.*, 1979). Although not essential for reproductive development (Nicholls *et al.*, 1988), photoperiodic changes allow young to be born or hatched at a time of year when food supply and environmental conditions favour survival. In order to overcome the effects of decreasing day length in regions where open sided poultry houses are common, meat-type breeding companies recommend slightly higher BW targets for their broiler breeders hatched "out of season" (July to December in the Southern hemisphere and January to June in the Northern Hemisphere). Photoperiodic responses consist of the transformation of photon energy to a neural transmitter, stimulating maturation of the hypothalamic-anterior pituitary-ovarian axis, and culminating in egg production. In mammals, photoperiodic changes detected by the eyes regulate pineal melatonin release, thereby controlling the photoperiodic response (Reiter, 1980; Nelson and Zucker, 1981; Follett, 1985). In birds, light is perceived by a yet unidentified extraretinal photoreceptor most likely in the hypothalamus (Menaker and Keatts, 1968). The pineal gland does not appear to be involved in the photoperiodic response in a number of species of birds, including the chicken. Pinealectomy was shown to have no effect on photoinduced gonadal development in the chicken (Johnson and van Tienhoven, 1984). In mammals, a biological clock is responsible, in part, for the regulation of reproductive function. The key component of this biological clock is the hypothalamic suprachiasmatic nucleus (Moore, 1983). Although not identified, birds are believed to have a similar biological clock that acts in concert with the extraretinal photoreceptors to regulate the neurons synthesizing and secreting GnRH for the transduction of photoperiodic information (Sharp, 1993).

Several studies reviewed by Nicholls *et al.* (1988) on the transformation of the light signal into a neural signal have yielded two key concepts; 1) short days are photoperiodically neutral and do not actively inhibit the activity of GnRH neurons and 2) long days are photoperiodically active and have both a stimulatory and an inhibitory effect on the GnRH neurons (Sharp, 1993). During short days, GnRH neurons act independently of the photoperiod. Exposure of photosensitive birds to long days stimulates GnRH neurons, stimulating additional gonadotrophin release from the anterior pituitary. Photosensitive

birds are birds which can convert the light signal in the form of photon energy into a neural signal. When this transformation ceases to occur, photorefractoriness is said to have set in. The bird cannot maintain her gonadotropin levels and reproductive function stops. It has been proposed that the decline in egg production after peak production is due to the gradual onset of photorefractoriness (Sharp *et al.*, 1992; Sharp, 1993). Photorefractoriness is characterised by the inability to further photostimulate the bird without first prolonged exposure (10-12 wk) to short days (Etches, 1996). Forced moulting can be used to overcome photorefractoriness.

Molting is a natural occurrence following egg production. Molt can be defined as the loss and replacement of feathers accompanied by the total regression of the reproductive organs and the cessation of lay (Johnson, 1986). As new feathers grow, old ones are forced out of their follicles. Moult can be induced by extreme stress, including feed and water withdrawal, major temperature changes and disease (Brake, 1993). During a molt there is a complete regression of the follicular hierarchy and loss of reproductive function. Luteinizing hormone secretion by the pituitary is reduced, leading to a reduction in ovarian progesterone and estrogen production (Boucek and Savard, 1970). At the same time, thyroxine and testosterone secretion have been shown to increase in turkeys (Scanes *et al.*, 1979). In addition to possibly inducing the molt, increases in thyroxine may play a role in thermoregulation during feather loss (Johnson, 1986). The requirement for thyroxine in the molting process is debatable (Johnson, 1986).

The secretion of GnRH from the hypothalamus into the hypothalamic portal system is dependent on the sum of stimulatory and inhibitory photoperiodic effects (Sharp, 1993). Continual exposure to short days will neither inhibit nor stimulate the GnRH neurons of the hypothalamus. GnRH neurons can actively secrete GnRH even under short days (Sharp, 1993). When photosensitive birds are newly exposed to long days, there is increased activity of GnRH neurons and subsequent stimulation of the release of LH and FSH from the anterior pituitary (Dawson *et al.*, 1985). However, while long days stimulate a rapid and complete switch "on" of all components, this is inevitably followed by a equally complete switch "off" (Nichols *et al.*, 1988). This gradual "switching off," can be referred to as the onset of photorefractoriness. Exposure to short days will accelerate this inhibition and gonadotropin levels would be reduced to the point where they can no longer support ovary function (Nicholls *et al.*, 1988).

Dawson *et al.* (1985) showed that starlings that were maintained on short days and subsequently exposed to 7 or more long days became refractory after a longer day photostimulation. Clearly, in the starling, the physiological changes that cause photorefractoriness are set in motion very soon after long day exposure and they tend to proceed regardless of subsequent changes in day length (Nicholls *et al.*, 1988). The specific duration of photoperiod that must be exceeded if photorefractoriness is to ensue in the chicken is unknown. Presumably due to selection for reproductive performance, modern broiler breeder hens would be much less sensitive to photorefractoriness than wild birds. Birds photostimulated with day lengths that are close to the critical day length required for a photostimulatory response may tend to; 1) remain in breeding condition longer (Stokkan *et al.*, 1982: Willow Ptarmigan and Red Grouse) and 2) exhibit high egg production persistency (Sharp *et al.*, 1992: dwarf broiler breeder). Photorefractoriness is most likely a species specific phenomenon and certainly wild birds are more sensitive to it than the domestic chicken. However, it is important to understand photorefractoriness to better characterize it in the domestic chicken. In broiler breeder laying trials at the University of Alberta, where individual egg production is recorded, photorefractoriness may be identified as different rates of persistence of lay after peak production (Sharp, 1993) or a complete cessation of egg production (Etches, 1996).

Previously it was shown that age at sexual maturity is dependent to some degree on physiological thresholds. Once these thresholds are met, the chicken initiates reproductive function even in the absence of a photostimulatory cue. However, the chicken's sensitivity to the photostimulatory cue may be another factor that is involved. The relationship between BW and sexual maturity has been described in terms of differences in photoperiodic drive (Follet and Nichols, 1984). A bird with a low photoperiodic drive would typically start laying later and at a larger body weight due to a slower response of the hypothalamic-anterior pituitary-ovarian axis to increasing day length. Based on this, Eitan and Soller (1994) proposed that selection for early onset of lay, as indicated by lower threshold BW at the onset of lay, may be associated with an increased photoperiodic drive. Eitan and Soller (1994) compared two lines selected for high or low threshold BW at sexual maturity and compared them to a commercial broiler breeder female line cross and a commercial egg-type cross. The low threshold BW line entered lay at a younger age and had greater egg production to 38 wk than the broiler breeder line cross. They postulated that decreased

photoperiodic drive may be a major factor contributing to poorer reproductive performance of the broiler breeder female line cross. Based on the rearing feed efficiency of the lines, they believe there exists a negative relationship between selection for juvenile growth rate and photoperiodic drive. Since a bird with a reduced photoperiodic drive may be less affected by high light intensity it would presumably have a reduced level of physical activity, which is well known to have a direct effect on feed efficiency. Selection for greater feed efficiency may have indirectly included a component of selection for a lower response to light stimulation, and hence a lower photoperiodic drive (Eitan and Soller, 1994). This may be another example of the negative effect of selection for growth characteristics on reproductive performance of the broiler breeder chicken.

1.2.8 Light Intensity

There have been a number of studies directed at identifying the intensity of light required to induce a photoperiodic response. Morris (1967) showed that egg production increased in a dose response manner from 0.2 to 5 lux with no effect of intensities over 5 lux on further increases in egg production. The hens perception of light is to some degree dependent on light intensity. The limits of light intensity required to define lights "on" and lights "off" for egg-type chickens and the effect on sexual maturity and egg production were investigated by Morris and Bhatti (1978). They concluded that light intensity of the photoperiod must be ten fold greater than the intensity of the scotoperiod in order for the birds to respond normally to the photoschedule. Recent work have demonstrated that modern SCWLs enter egg production in a highly uniform manner regardless of light intensity (1 lux to 500 lux) compared to non-selected random bred SCWLs (Oosterhoff and Robinson, AFNS, University of Alberta, Edmonton, Alberta, T6G 2P5, personal communication). Similar work with broiler breeders suggest that 10 lux of light is adequate for normal sexual development (Muller *et al.*, 1996). Since 10 lux was the lowest light intensity used in the study, the threshold for normal photoperiodic response, as in SCWL, may be even less.

1.2.9 Environmental Control of the Ovulatory Cycle

The control of ovulation involves interaction between follicular maturation and the light and dark

cycles perceived by the bird. Before ovulation can occur, the follicle must be sufficiently mature to signal the hypothalamus which in turn will only respond to the follicular signal at certain times within the circadian rhythm (Etches, 1984). This period of response is known as the open period for LH release (Etches, 1984). Both of the systems that regulate the ovulatory cycle are independent and asynchronous (Fraps, 1965; Etches, 1984).

As discussed earlier, birds can ovulate and oviposit in the absence of a photostimulatory cue. Similarly, birds will continue to lay eggs in constant darkness or illumination (Bhatti and Morris, 1978a). However, in order to prevent the free running of the ovulatory cycle, birds are naturally and normally under commercial conditions, exposed to periods of light and dark in order to initiate and maintain the circadian system. Feed cycles, noise and temperature may also act as environmental cues (Cain and Wilson, 1974). Dusk, or the light-dark transition, appears to be the cue responsible for the timing of oviposition (Bhatti and Morris, 1978b). Timing of oviposition can be achieved with as little as 1.25 h of dark (Etches, 1990). Regardless of position of the photoperiod within the solar day, when hens are maintained under 14L:10D the majority of hens will lay within the first few hours of the photoperiod (Etches 1990). Ovulatory patterns will follow a shift of the photoperiod within the solar day within 2 or 3 d of the shift. Excessively long scotoperiods will result in more eggs being laid outside of the photoperiod (Naito *et al.*, 1980).

1.2.10 Rules and Exceptions for the Ovulatory Cycle

Hens lay eggs in sequences of one or more eggs where subsequent eggs are laid on consecutive days and sequences are separated by one or more pause days. Typically, the first egg of a sequence would be laid within 1 to 3 h of lights on (Etches and Schoch, 1984). Eggs are laid later on consecutive days until an egg is laid so late that the F1 follicle progesterone signal following oviposition does not elicit a response by the hypothalamus (end of the open period). Ovulation will occur within 0.25 to 0.45 h after oviposition (Warren and Scott, 1935) except for the terminal oviposition in a sequence.

Using the egg-type hen as a model, Etches (1990) summarized the basic rules of the ovulatory cycle. 1) Sequential ovulations are separated by 24 to 28 h. 2) All follicles except the largest are non-

ovulable. 3) Once the largest follicle has ovulated and the second largest had assumed it's position in the hierarchy, a physiological maturation begins. 4) Maturation involves the acquisition of the ability of the largest follicle to ovulate in response to the preovulatory surge of LH. 5) Follicles are irrevocably committed to ovulate once they begin to accumulate yellow yolk. 6) Under normal conditions, oviposition occurs within the photoperiod.

Meat-type hens do not follow the ovulatory cycle rules as closely as egg-type hens. The following ovulatory cycle events are exceptions to the preceding rules and are commonly seen in the laying patterns of broiler breeder hens, particularity when over fed. 1) Large yellow follicles are arranged in multiple hierarchies in which there is more than one follicle of similar size. Overfeeding during rearing and breeding results in increased follicular recruitment leading to a large number of LYF, some of which are of similar sizes (Yu *et al.*, 1992b, Hocking *et al.*, 1987, 1989; Hocking 1993). 2) Multiple ovulations can occur within minutes or hours of each other. Yu *et al.* (1992c) showed that in some cases the F1 and the F2 follicles of full fed hens were functionally the same. Both follicles were capable of producing high levels of progesterone with low level production of androstenedione. 3) Eggs are often laid late in the photoperiod or into the scotoperiod (Yu *et al.*, 1992b). Since there can be more than one ovulable follicle, erratic ovulations can occur early and late within the same open period for LH release. 4) Sequences may be separated by more than one pause day. Irregularities in follicular recruitment and high rates of atresia may result in times when there are no ovulable follicles on the ovary resulting in long egg laying pause lengths as observed in over fed broiler breeders (Robinson *et al.*, 1993b). Feed restricted broiler breeder hens typically lay fewer eggs in more shorter sequences than SCWL hens fed *ad-libitum*. Average sequence lengths for feed restricted broiler breeder hens are less than half (4.1 d) what they are for egg-type hens (9.7 d) (Robinson *et al.*, 1990; Robinson *et al.*, 1993b). 5) Large yellow follicles can avoid ovulation through atresia. Atresia of yolky follicles are characteristic of over fed broiler breeder hens and atresia is positively correlated to BW at sexual maturity (Hocking, 1993). These phenomenon serve to describe the condition know as erratic ovulation defective egg syndrome (EODES) and the relatively poor egg production characteristic of a meat-type breeder hen (Jaap and Muir, 1968; Hocking *et al.*, 1987; Yu *et al.*, 1992b; Robinson *et al.*, 1993b).

1.3 BROILER BREEDER MANAGEMENT

1.3.1 Introduction

The majority of information on which primary breeders base their management guides in the past came from "in house" research facilities and field experience, neither of which, for reasons of information security or suitability, contributed significantly to the published literature. Over the last decade there has been substantial information published on fine tuning the management programs of broiler breeder hens. However, considering the differences between the different strains of broiler breeders, the rapid genetic turnover of the lines, the high degree of speciality of different commercial birds within a strain, and the relatively small number of research groups studying this area, it is difficult to make management recommendations for all types of broiler breeders. One broiler breeder husbandry program can no longer be used for all strains of chickens. This section deals with the current state of knowledge regarding understanding the modern broiler breeder hen in terms of; 1) performance objectives, 2) fertility and sperm storage, 3) effect of aging, 4) effects of *ad-libitum* feeding, and 5) fine tuning feed restriction programs.

1.3.2 Performance Objectives

Total egg numbers, proportion of unsettable eggs, age at first egg, chicks per hen and peak egg production are all classical ways of evaluating broiler breeder reproductive performance. However, managing a broiler breeder really involves managing her ovulatory cycle and the ovary itself. Blake and Ringer (1987) characterized the effect of ahemeral (not 24 h) light-dark cycles on egg formation, oviposition lag time and egg laying sequence length (period of consecutive ovipositions which are terminated by a pause of one or more days) in pheasant hens. They found that while longer ahemeral light-dark cycles increased egg formation time, overall increases in egg production and egg laying sequence length were realized because of fewer egg laying pauses between sequences. Robinson *et al.* (1990) established the use of laying sequence analysis as a tool to evaluate reproductive performance in the chicken. By measuring sequences of an individual hen, one can derive profiles of sequence length and pause length over the laying period (Robinson *et al.*, 1993b). Hens who lay more eggs typically lay those

eggs in longer sequences separated by fewer pause days (Robinson *et al.*, 1990). There is also a significant correlation (r = 0.385) between egg production and the length of the prime sequence (Robinson *et al.*, 1990).

1.3.3 Aging

The egg production rates of both egg-type and meat-type hens are reduced as they age past peak production. It is commonly accepted within the industry that while overfeeding broiler breeders from the time of sexual maturity to peak egg production will enhance egg production peaks, it lowers the persistency of lay (Mark Newcombe, Shaver Poultry Breeding Farms Ltd, Cambridge, Ontario, Canada NIR 5V9, personal communication). Reduced rates of egg production associated with increased age have been attributed to a reduction in the rate of follicular maturation (Johnson *et al*, 1986), an increase rate of follicular atresia (Palmer and Bahr, 1992), onset of photorefractoriness (Follet and Nichols, 1984) and a reduced sensitivity of the neural mechanisms controlling the basal secretion of GnRH (Williams and Sharp, 1978a). Williams and Sharp (1978a) have proposed that since the observed decrease in the baseline concentration of plasma LH in old egg-type laying hens is not due to a decline in the response of the anterior pituitary to GnRH secretion from the hypothalamus, the lower baseline concentration of plasma LH may be due to a reduced action of the neural mechanisms controlling the basal secretion of GnRH. The reduced GnRH secretion may be due to a reduced sensitivity of the hypothalamus to progesterone. If the reduced rate of lay after peak production is due to a reduced sensitivity to light stimulation (Follet and Nichols, 1984), the resulting reductions in gonadotropic secretions may increase rates of atresia as in mammals (Richards, 1987) as well as reduce rates of follicular recruitment (Williams and Sharp, 1978a) and maturation (Johnston *et al.*, 1986). This has been supported by treating old egg-type hens with high doses of pFSH, which has been shown to increase numbers of growing follicles, decrease numbers of atretic follicles, and increase yolk deposition (Palmer and Bahr, 1992). Thus indicating the possibility of inadequate stimulation of the ovary by FSH either mediated through reduced FSH receptor activity or FSH secretion by the anterior pituitary. The role of FSH in follicular recruitment in broiler breeder hens has not been investigated.

1.3.4 Effect of Ad-Libitum Feeding

Full fed commercial broiler breeders lay fewer eggs, lay more defective eggs, have reduced levels of fertility and hatchability, and are more prone to reproductive complications causing death than feed restricted broiler breeder hens (Robinson *et al.*, 1993b). *Ad-libitum* feeding treatments have been used extensively to evaluate the effect of feed allowance on reproductive performance. Early work suggested that in order to maximize economic returns, any restriction in total nutrients during the laying period of a broiler breeder hen would need to be small and not imposed before the time of peak production (Pym and Dillon, 1974). However, more recent studies have shown that *ad-libitum* feeding of broiler breeders, while advancing age at sexual maturity, is detrimental to hen livability, total egg production, fertility and hatchability (Hocking, 1993; Katanbaf *et al.*, 1989; Robinson *et al*, 1991b; and Yu *et al.*, 1992a, 1992b).

From research published by Hocking *et al.* (1987, 1989), Hocking (1993), Robinson *et al.* (1991a, 1991b), and Yu *et al.* (1992a, 1992b, 1992c) it is clear that feed restriction during the rearing and breeding periods improves reproductive performance through control of the development of the ovarian large follicular hierarchy. A reduction in the number of LFY at sexual maturity through the use of feed restriction is associated with a subsequent increased rate of lay (Hocking *et al.*, 1987; Yu *et al.*, 1992b). Some rather dated reports that claim a benefit of *ad-libitum* feeding during part or all of the breeding period on performance (Bornstein and Lev, 1982) are not based on egg production performance through to the end of lay (60 plus wk of age). The effect of an earlier age at sexual maturity of full fed hens, and the higher peaks sometimes associated with overfeeding represent a high proportion of the total eggs produced when recording stops prematurely. Take for example a modern broiler breeder egg production curve (Anonymous, 1994d). Of the 190 total eggs that a hen is predicted to produce to 66 wk of age, only 50 of them are produced through peak production to 34 wk of age. The other 140 are produced from 34 to 66 wk of age. A 1% reduction in hen day production through the post peak period would have to be offset by a increase in the 2 wk peak of 10% in order to maintain the same total egg numbers.

Robbins *et al.* (1986) demonstrated that broiler females (not a broiler breeder) that were feed restricted to 24 wk and fed *ad-libitum* thereafter to 68 wk of age had significantly higher egg production than birds fed *ad-libitum* throughout, fed *ad-libitum* and restricted after 24 wk of age or feed restricted

throughout. However, the degree of feed restriction appears to have been too severe to allow for normal ovarian function and bird growth. In a later report by Robbins *et al.* (1988), they provided evidence that a commercial broiler breeder fed *ad-libitum* during lay had reduced levels of egg production to 64 wk of age when compared to a feed restriction program as outlined by the breeder. Using commercial strains and following accepted management guidelines on feed restriction, McDaniel *et al.* (1981b), Robinson *et al.* (1991b) and Yu *et al.* (1992b), reported lower egg production associated with *ad-libitum* feeding. It is important to note that three of the four authors used different strains of broiler breeders (Robbins *et al.*, 1988: Peterson Farms; McDaniel *et al.*, 1981b: Hubbard Farms; Robinson *et al.*, 1991b and Yu *et al.* 1992b: Indian River). In the same way that modern strains exhibit increasing severe problems when allowed to full feed than strains used in earlier research (Robinson *et al.*, 1993b), different strains may respond differently to full feeding treatments.

In 1987 Hocking *et al.* reported that low egg production in dwarf broiler breeder hens fed *ad-libitum* during rearing was associated with an excess rather than a deficiency of ovulable yellow follicles at first egg (6.8 vs 9.0) and at 30 wk of age (5.6 vs 7.3) when comparing feed restriction and *ad-libitum* programs respectively. However, numbers of LYF were the same between the *ad-libitum* and feed restricted hens at 45 wk of age (4.4 vs 3.8) and at 60 wk of age (4.0 vs 4.0). This was supported by subsequent work by Hocking *et al.* (1989) with normal broiler breeders. Feed restriction during rearing reduces the number of LFY in the ovary, leading to a reduction in the number of LYF of similar weight, resulting in production of fewer unsettable eggs (Robinson *et al.*, 1993b). Yu *et al.* (1992b) reported that feed restriction during rearing, breeding or both, significantly reduced the incidence of erratic laying (ovulations occurring outside of the prime laying period). The incidence of erratic ovipositions was strongly correlated with soft shelled and shelless egg production and negatively correlated with settable egg production. In a companion paper Yu *et al.* (1992c) reported that both the F1 and the F2 of some full fed broiler breeder hens were capable of producing high levels of progesterone with low level production of androstenedione. Thus, full fed hens appear to have both a reduced dependence on the circadian rhythm in controlling the open period for LH release as well as more than one LYF in the ovary sufficiently mature to respond to the LH surge.

Perhaps one of the more dramatic examples of the effect of over feeding on ovarian morphology is provided by Robinson *et al.* (1993a). They found that 40 wk old laying broiler breeder hens allowed to full feed for only 7 d showed a significant increase in BW, liver weight, liver fat content, plasma lipid content, ovary weight and the incidence of LYF of similar size. After 14 d of *ad-libitum* feeding, significant increases were also seen in absolute fatpad weight, individual weights of the F1 to F4 LYF, as well as the number of LYF in the ovary. No effect on egg production was seen during the 14 d study.

1.3.5 Fertility

Following insemination, spermatozoa are subject to selection, storage and transport to the infundibulum, the site of fertilization (Brillard, 1993). The duration of fertility is dependent in part on the numbers of sperm residing in the sperm storage tubules after artificial insemination (AI) or copulation (Brillard, 1993). Egg-type chickens with a higher rate of lay tend to have a longer duration of fertility than do egg-type chickens with a lower rate of lay (Beaumont *et al.*, 1992). Beaumont *et al.* (1992) suggested that there is a strong positive correlation between laying rate and duration of fertility in both egg-type and meat-type hens.

Hens that produce few eggs in short sequences will have proportionally more first of sequence eggs. Fasenko *et al.* (1992) and Robinson *et al.* (1991a) have shown that in broiler breeder hens, first of sequence eggs have a reduced level of embryonic viability, possibly because the female germ cell of the first of sequence egg is 1 d older at ovulation than the female germ cell of a mid-sequence egg. The effect of *ad-libitum* feeding broiler breeder hens on increasing the number of sequences and reducing the length of sequences may play a role in reducing the overall hatchability of eggs from these hens. Lerner *et al.* (1993) also found that in turkey hens first of sequence eggs are of lower shell quality compared with eggs laid subsequently. Lerner *et al.* (1993) determined that shell quality negatively influenced fertility, hatchability and embryo viability.

Fertility is negatively affected in broiler breeder hens that are excessively above target BW (Yu *et al.*, 1992b). While comparing artificially inseminated feed restricted and full fed broiler breeders, Yu *et al.* (1992b) found that full fed hens produced fewer total and settable eggs and had lower percentages of

egg fertility, hatchability and embryo viability. It has been speculated that since differences in BW of broiler breeders are predominantly due to differences in fat, accumulations of fat in the uterovaginal junction may reduce the duration of fertility by reducing the storage capacity of the sperm storage glands (McDaniel *et al.*, 1981a). Bilgili and Renden (1985) showed that high BW in broiler breeder hens was negatively correlated with the percent fertile eggs of total eggs laid over 21 d, the duration of fertility, and fertile egg production. However, oviduct fat content and measures of fertility were not found to be significantly correlated. It was suggested that the adverse effects of percent or total body fat on fertility involves mechanisms other than increased oviduct lipid accumulation as speculated by McDaniel *et al.* (1981a). It can be difficult to identify factors which have an effect on the duration of fertility in frequently inseminated hens.

1.3.6 Fine Tuning Feed Restriction and Photostimulation Programs

Feed allocations are only as accurate as the BW measurements that they are based on. Although all primary breeders recommend some form of feed restriction during both the rearing and breeding periods to control BW, few are specific about what time of day is best to weigh the birds. Fattori *et al.* (1992) sampled 8 and 10 wk old broiler breeder pullets on the non-feed day of a skip-a-day feeding program. They showed that time of weighing was an important source of variation in BW. Body weight measurements taken at different times on a non-feed day were not comparable.

Despite primary breeders recommendation for attentive BW monitoring and feed allocations to meet changing target growth curves, there is little published information on the effects of small differences in BW target or feed allocation. In a series of studies by Fattori *et al.* (1991a, 1991b, 1993) the response of broiler breeder females to feed restriction below recommended levels was assessed. Birds were fed to target weights 8% above standard BW, standard BW, and 8, 16, and 24% below standard BW through to 62 wk of age. They provided evidence that for every 13.7 g decrease in BW there was a corresponding delay in flock maturity (50% production) by 1 d, supporting previous work by Pearson and Herron (1982). The most severe level of feed restriction treatment resulted in significantly fewer double yolked eggs than from the standard BW target birds and significantly smaller egg size to 46 wk of age. However, feed

restriction had no effect on fertility, hatchability, mortality, or egg weight to 62 wk of age. Birds feed restricted at greater levels were laying at higher levels late in lay than standard BW or 8% above standard BW feed treatments. While the greater feed restricted birds entered lay later, they had higher levels of egg production at 62 wk of age and were considered to have acceptable levels of egg production to an older age. In addition they reported an economic advantage of higher levels of BW restriction.

Hocking (1993) investigated the effect of different BW targets, on the ovarian follicular hierarchy. In addition to an *ad-libitum* and a commercial feed restriction program treatment (1500 to 2400 g gain from 14 to 22 wk of age), he allocated different quantities of feed to maintain (2800 g or 3800 g), lose (3800 to 2800 g), or gain (2800 to 3800 g) BW from 14 to 22 wk of age, respectively. In agreement with previous studies (Hocking, 1992), he showed that the number of LYF at first egg was directly proportional to BW within the the variety of feeding regimes examined. Birds held to commercial feed restriction levels between 14 and 22 wk of age had 6.3 LYF at first egg compared to 10.7 for birds of an *ad-libitum* treatment. The commercially restricted birds also had the lowest incidence of internal ovulation.

Wilson *et al.* (1995) devised three rearing feed allocation programs to result in divergent BW curves form 1 to 14 wk of age with all curves converging to a common BW target at 24 wk of age. They appropriately called their treatments early slow (concave curve), standard or linear growth, and early fast (convex curve). Maximum BW differences ($\pm$ 500 g of standard) were realized at 13 to 14 wk of age after which time the curves began to converge. Although there was no difference in LFY numbers at 25 or 58 wk of age, the early slow birds laid fewer eggs and had the lowest hatchability in spite of being the same BW as the other two treatments from 24 wk of age on.

Robinson and Robinson (1991) sorted broiler breeders based on 21 wk BW and, keeping feed allocations the same, monitored the reproductive performance of the low, medium and high weight birds representing normal variation of BW occurring within a flock. Differences in BW were in the range of $\pm$ 300 to 400 g of medium weight through to 62 wk of age. The low birds laid fewer eggs than the medium or the high weight birds. There was no difference in the fertility or hatchability results. The authors concluded that flocks with a high proportion of low weight birds may exhibit poor production efficiency.

Wautier (1994) investigated the effect of different ages at photostimulation on reproductive

performance. All broiler breeder pullets were grown on the same BW curve and photostimulated at 120, 130, 140, 150 or 160 day of age. As age at photostimulation increased, the interval between photostimulation and sexual maturity decreased. Those pullets photostimulated earlier had lower levels of carcass fat content at photostimulation, yet all photostimulatory groups had similar levels of carcass fat content at sexual maturity. Photostimulation before 140 d negatively affected numbers of chicks produced per hen.

Recently, Yuan *et al.* (1994) investigated the relationship between increasing BW target and early photostimulation. They hypothesised that allowing broiler breeder pullets to attain greater than recommended BW targets, accompanied by early photostimulation, would reduce rearing time and maximize settable egg production (egg weight > 50 g). The three BW targets consisted of *ad-libitum* feeding, and linear growth to a BW of 2800 or 2300 g at 20 wk of age. Birds were either photostimulated at 14, 17 or 20 wk of age. The breeder recommended photostimulation at 20 wk of age at a BW of 2000 g. Age at sexual maturity was advanced 2 wk by both the 14 and the 17 wk photostimulation age when compared to the 20 wk photostimulation age. Total eggs produced to 64 wk of age for the *ad-libitum* (124) was less than produced by either of the other two BW treatments (152 eggs for 2800 g at 20 wk and 156 eggs for 2300 g at 20 wk). In spite of the earlier onset of lay attributed to early photostimulation, none of the photostimulatory treatments were different with respect to total egg production (14 wk = 140, 17 wk =145, and 20 wk = 148). They attributed the negative correlation between the age at photostimulation and total egg production to the poorly understood negative effect of early maturation on later egg production levels described by Leeson and Summers (1980).

While differences in feed allocation are often used to create differences in BW, different rates of feed allocation are commonly used to achieve similar BW targets. Robinson *et al.* (1995) examined the effect of fast feeding (rapid increases in feed allocation) versus slow feeding (gradual increases in feed allocation) in the period of 20 to 25 wk of age as well as the effect of slow photostimulation (step up increases in day length) with fast photostimulation (one step increase in day length) on reproductive performance. They found that the effects slow photoperiod and fast feeding increased ovary weight at sexual maturity, and fast feeding increased numbers of LYF from 7.9 to 8.9 at sexual maturity. Yet, there

was no difference in age, BW or abdominal fatpad weight at the time of sexual maturity. There was a 10.9 egg reduction in the fast feeding program that was associated with the reduced control of the follicular recruitment process prior to sexual maturity. The fast photostimulation hens had an unexplained reduction in hatchability of settable eggs and hatchability of fertile eggs set compared to the slow photostimulation hens. In the first report of it's kind, Robinson *et al.* (1995) demonstrated that ovarian development is very sensitive to relatively minor differences in feed allocation presumably independent of BW.

1.3.7 Conclusions

All of these reports serve to emphasise the high degree of sensitivity of the broiler breeder female to different feeding and photostimulatory programs. Determining the influences of different management programs on reproductive performance is somewhat of a difficulty. By the time the research is complete and the results complied, the strain of broiler breeder used is two years out of date and the information gained not universally applicable to all strains of broiler breeders. Yet, information such as that summarized here is vital to developing new management programs for female broiler breeders.

As long as the selection criteria for parent females includes selection for growth parameters, the broiler breeder industry will continue to place importance on fine tuning feed restriction programs in order to maximize chick production. As the broiler chick evolves, so must the broiler parent. As this occurs, broiler breeder management programs must continue to change and evolve as well.

1.4 INTRODUCTION TO CHAPTERS

Based on the current state of knowledge of avian reproductive physiology, broiler breeder management, and the key research objectives of the University of Alberta broiler breeder research group, three separate experiments were conducted. In Chapter 2 I aimed to provide evidence of the well accepted but poorly documented hypothesis that *ad-libitum* fed birds have a lower duration of fertility than feed restricted birds. Chapter 3 was completed to provide some of the necessary background for the work presented in Chapters 4 and 5. The effect of time of weighing on BW needed to be evaluated in order to impose the effect of small differences in BW necessary for the experimental design. I also wanted to illustrate the importance of weighing procedure in determining the appropriate feed allocation. Chapter 4 and 5 represent a substantial portion of the research. They served to evaluate the effect of some of the recent trends in broiler breeder management at the level of the bird on carcass traits, ovarian morphology and reproductive performance. The objectives of the individual chapters of this thesis are as follows.

Chapter 2: To determine the effect of *ad-libitum* feeding late in lay on the duration of fertility in caged broiler breeder hens.

Chapter 3: To determine if time of weighing has a significant effect on mean BW in skip-a-day fed 10 wk old broiler breeder pullets.

Chapter 4: To observe the influence of small changes in BW target and age at photostimulation on carcass traits and ovarian morphology at photostimulation and at sexual maturity in broiler breeders.

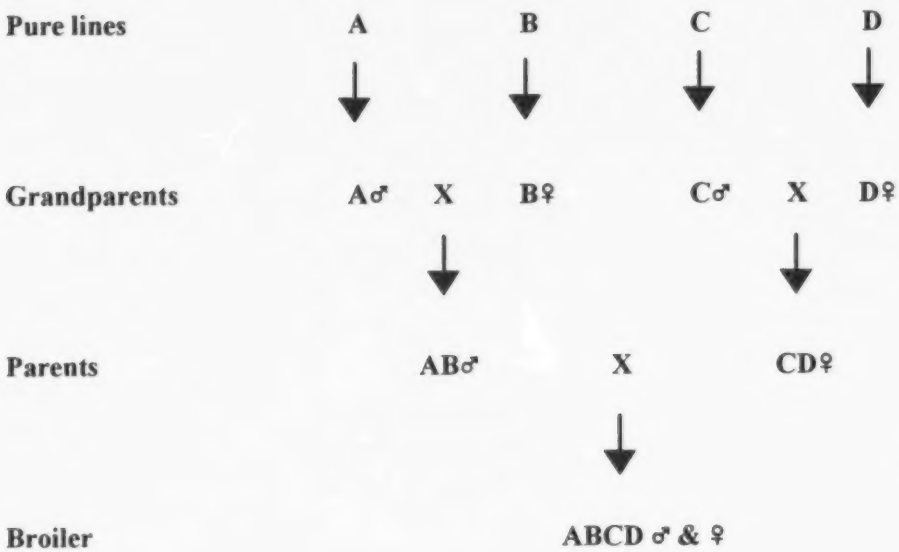
Chapter 5: To observe the influence of small changes in growth curve and age at photostimulation on reproductive performance, and carcass traits and ovarian morphology at 61 wk of age. To determine the relationship between carcass traits and ovarian morphology at 61 wk of age with previous reproductive performance.

TABLE 1-1. Potential performance of the 1994 Shaver Starbro parent female to 61 wk of age (Anonymous, 1994) and of the 1993 Shaver Starbro broiler to 42 d of age (Anonymous, 1993a)

Shaver Starbro parent female	
Age at 50% production (average age at first egg)	26.5 wk
Age at peak egg production	29 through 30 wk
Peak hen day (H.D.)[1] egg production	84 %
Cumulative number of eggs per hen housed (H.H.)[2]	171.7
Percent hatching eggs	93.7 %
Cumulative hatching eggs per H.H.	160.9
Average hatchability	84.9 %
Broiler chicks hatched per H.H.	136.6
Shaver Starbro broiler	
Body weight (g)	1945 - 2010
Feed Conversion Ratio (feed / gain)	1.82 - 1.85

[1] Hen day (H.D.) egg production is based on the total eggs produced divided by the number of hens currently in the house.
[2] Hen housed (H.H.) production is based on the production parameter expressed as a percentage of the total number of hens housed. Birds that have been culled or have died since housing are included in calculation.

FIGURE 1-1. Standard four-way cross used in the meat-type chicken breeder industry to produce a commercial broiler. Broiler chickens are the product of a terminal cross between the hybridized male of the male line and the hybridized female of the female line (adapted from Hunton, 1990).



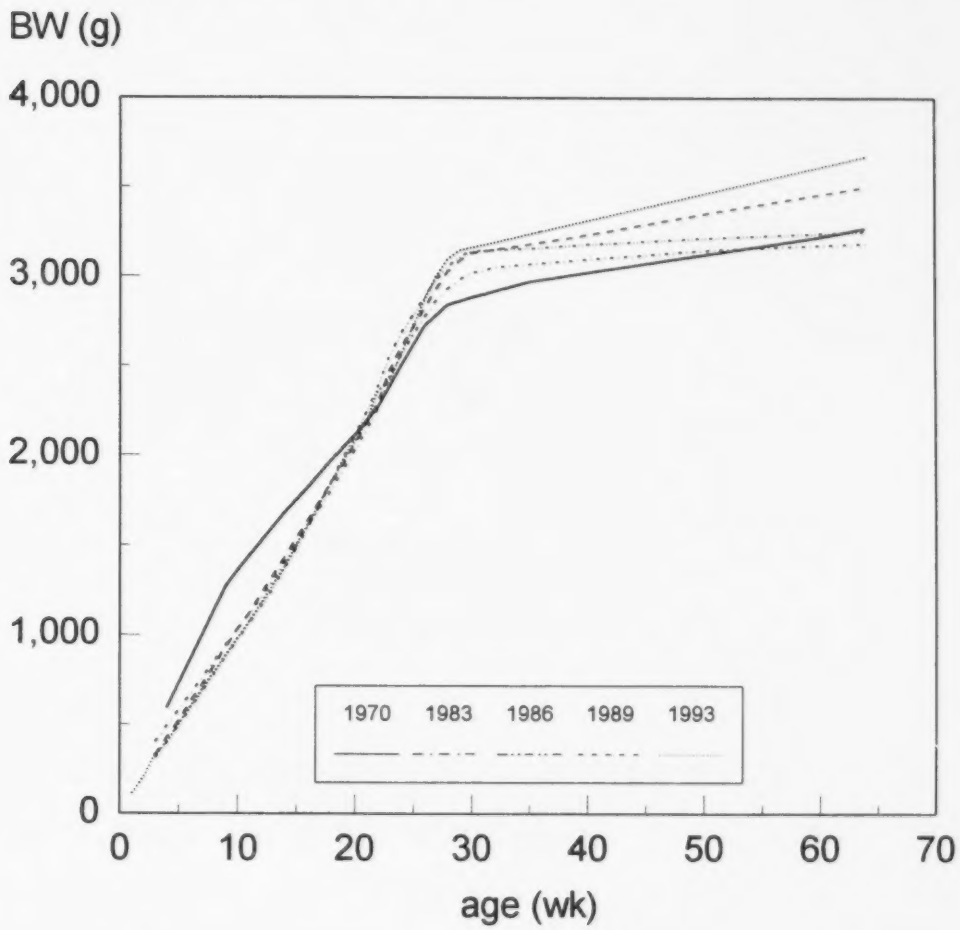


FIGURE 1-2. Body weight targets for Shaver Poultry Breeding Farms' female broiler parent from 1970, 1983, 1986, 1989 and 1993.

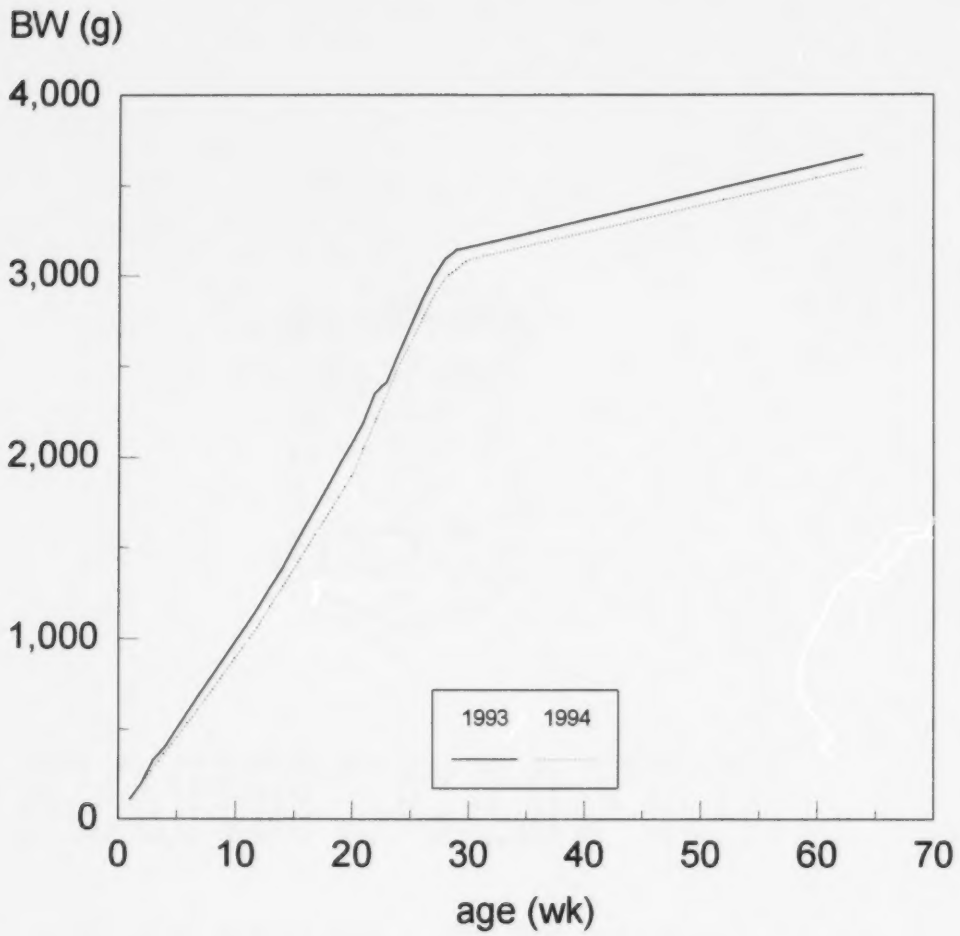


FIGURE 1-3. Body weight targets for Shaver Poultry Breeding Farms' female broiler parent from 1993 and 1994.

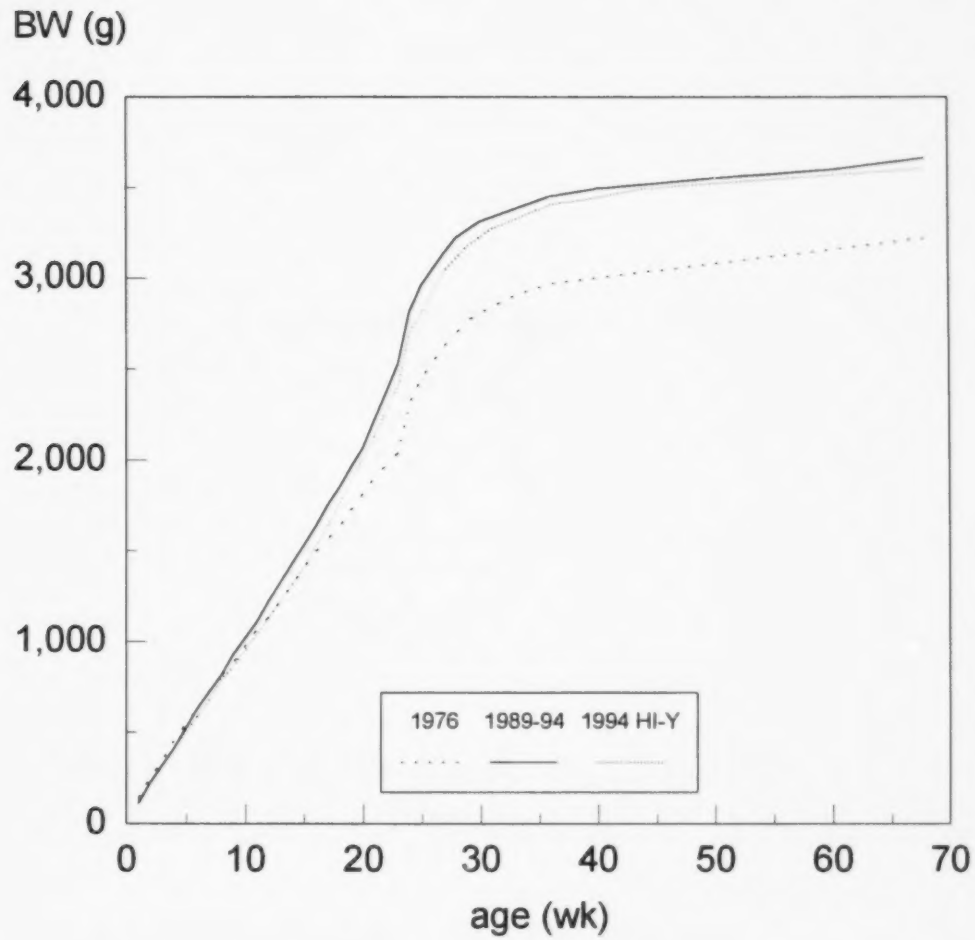


FIGURE 1-4. Body weight targets for Hubbard Farms' female broiler parent from 1976, 1989 through 1994, and 1994 HI-Y (Hi-Yield).

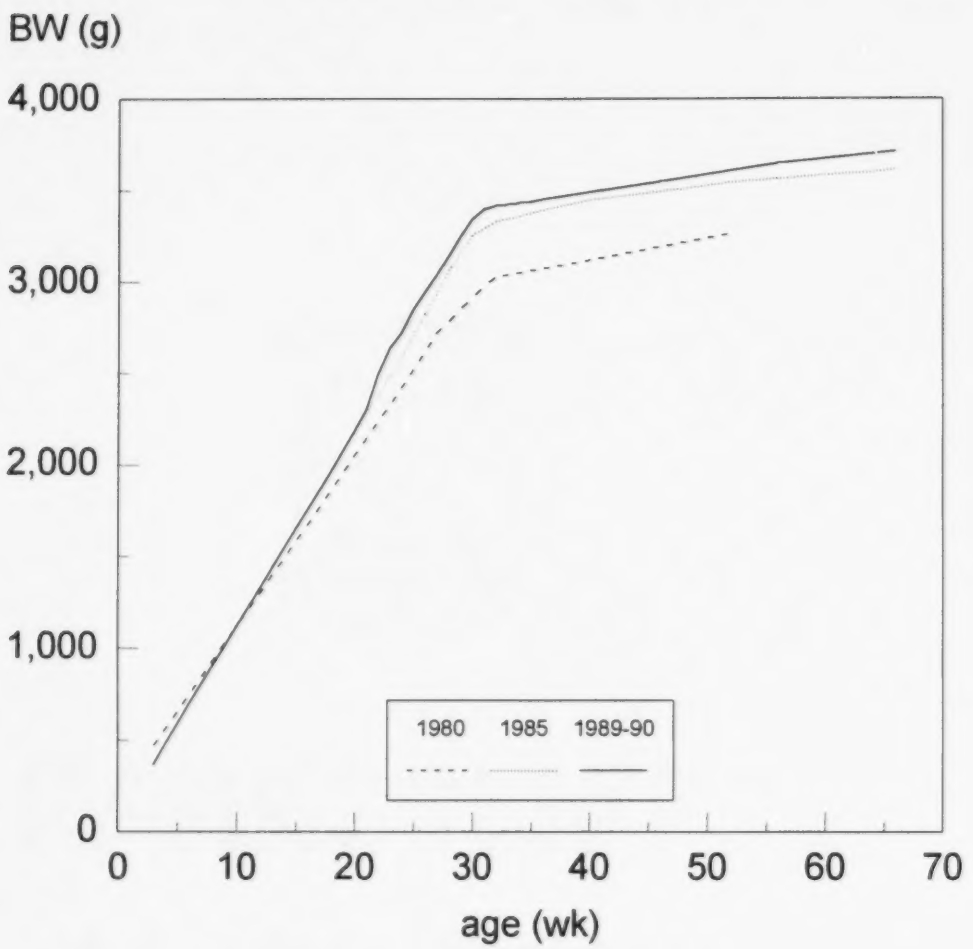


FIGURE 1-5. Body weight targets for Arbor Acres Farms' female broiler parent from 1980, 1985 and 1989/90.

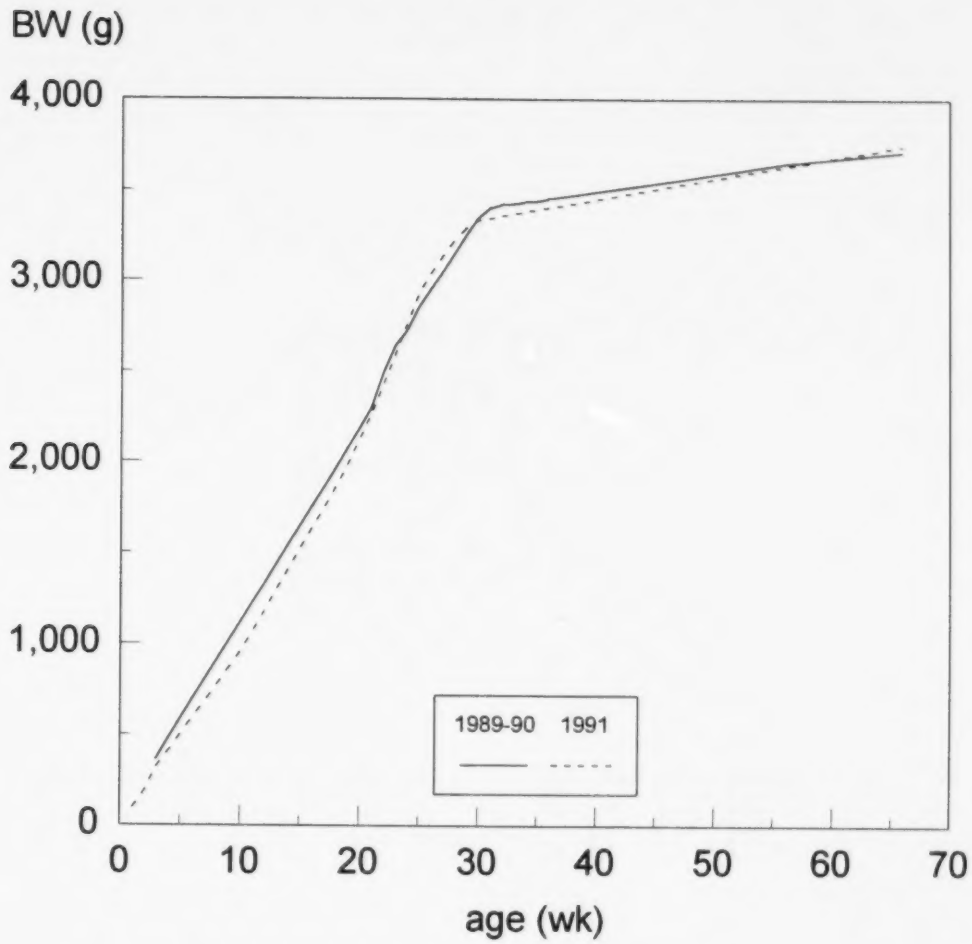


FIGURE 1-6. Body weight targets for Arbor Acres Farms' female broiler parent from 1989/90 and 1991.

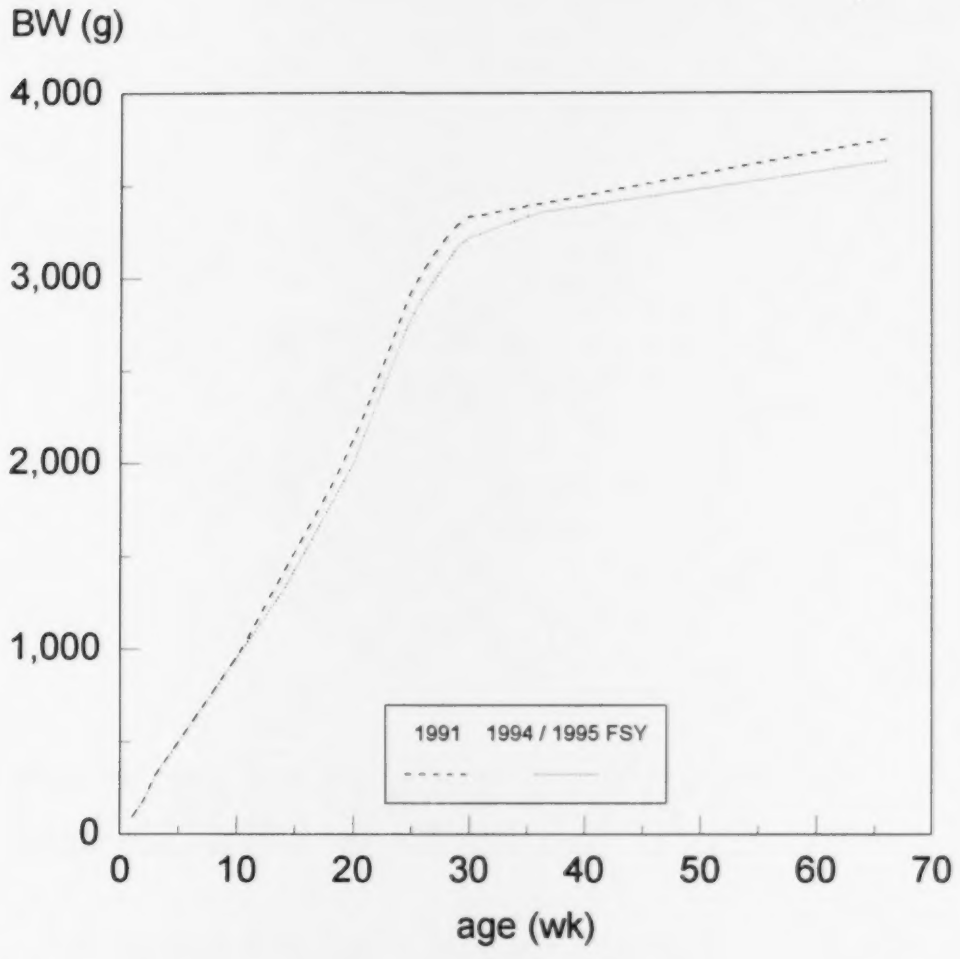


FIGURE 1-7. Body weight targets for Arbor Acres Farms' female broiler parent from 1991, 1994, and 1995 FSY (Feather Sexable Yield). The 1994 and the 1995 FSY BW targets are the same.

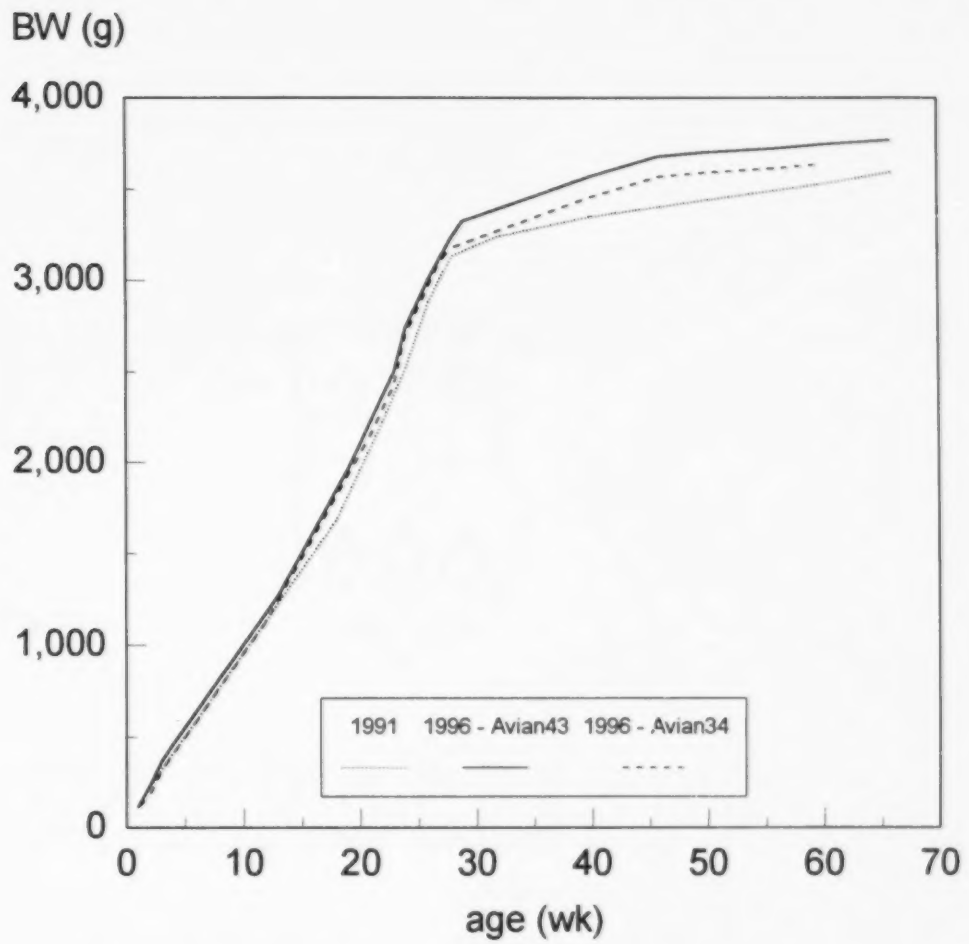


FIGURE 1-8. Body weight targets for Avian Farms International female broiler parent from 1991 and 1996 (Avian43 and Avian34).

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2. DURATION OF FERTILITY IN *AD-LIBITUM* AND FEED RESTRICTED CAGED BROILER BREEDER HENS [1]

2.1 INTRODUCTION

The factors that affect the length of time that spermatozoa can remain viable in the oviduct of the modern broiler breeder chicken following artificial insemination or natural mating have not been clearly defined. Following insemination, spermatozoa are subject to selection, storage and transport to the infundibulum, the site of fertilization (Brillard, 1993). The duration of fertility is dependent in part on the numbers of sperm residing in the sperm storage tubules after artificial insemination (AI) or copulation (Brillard, 1993). Egg type chickens with a higher rate of lay tend to have a longer duration of fertility than do egg type chickens with a lower rate of lay (Beaumont *et al.*, 1992). Beaumont *et al.* (1992) suggested that there is a strong correlation between laying rate and duration of fertility in both egg and meat type hens.

Fertility is negatively affected in broiler breeder hens that are excessively above target BW (Yu *et al.*, 1992). While comparing artificially inseminated feed-restricted and full-fed broiler breeders Yu *et al.* (1992) found that full-fed hens produced fewer total and settable eggs and had lower percentages of egg fertility, hatchability and embryo viability. It has been speculated that since differences in BW of broiler breeder hens are predominantly due to differences in fat, accumulations of fat in the uterovaginal junction may reduce the duration of fertility by reducing the storage capacity of the sperm storage glands (McDaniel *et al.*, 1981). Bilgili and Renden (1985) showed that high BW in broiler breeder hens was negatively correlated with the percent fertile eggs of total eggs laid over 21 d following insemination, the duration of fertility and fertile egg production. However, oviductal fat content and measures of fertility were not found to be significantly correlated. They suggested that the adverse effects of percent or total body fat on fertility involves mechanisms other than increased oviductal lipid accumulation as speculated by McDaniel

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[1] A version of this chapter has been published (Goerzen, P. R., W. Julsrud, and F. E. Robinson, 1996. Duration of fertility in *ad-libitum* and feed restricted caged broiler breeder hens. Poultry Sci. 75:962-965).

et al. (1981). It can be difficult to identify factors which have an effect on the duration of fertility in frequently inseminated hens. This study was undertaken to investigate the effects of excess BW on the duration of fertility in laying broiler breeder hens.

2.2 MATERIALS AND METHODS

Sixty Shaver Starbro hens were randomly selected at 52 wk of age from a flock of 180 hens. The birds had been raised to 52 wk of age following accepted guidelines of beak trimming, wing banding at 4 wk of age, feed restriction to maintain body weight at breeder target levels, individual bird weighing weekly and artificial insemination. The birds were reared in floor pens to 20 wk of age at which time they were individually caged. The cages were 51.0 cm by 45.7 cm with a sloped floor. The hens had ample room to stand fully erect. The flock was photostimulated at 20 wk by increasing the day length from 8 h to 15 h in a single step. The flock was fed a standard broiler breeder starter and grower ration during the rearing period. At 20 wks of age a breeder ration with 16.3% CP, 2738 kcal ME/kg, and 3.46% Ca was provided.

The 60 hens were individually weighed and randomly assigned to one of two treatments. Thirty hens were feed restricted (R) to maintain breeder recommended BW targets. Feed was allocated daily on a individual basis. The second treatment consisted of feed allocation on a full fed (F) basis. All birds were weighed individually each week. The first study began after a 4-wk acclimation period (52 to 56 wk of age).

Two study periods were conducted (56 to 60 wk of age and 60 to 64 wk of age). When the hens were 56 or 60 wk old they were inseminated once at 1300 h on each of two consecutive days with 0.05 ml of pooled broiler breeder chicken semen. No further inseminations were conducted for the following 26 d period. The study period began the day following the second insemination. This was the earliest time an egg fertilized with sperm from the first insemination day could be oviposited. Prior to the start of Study 1 all of the hens had been inseminated weekly with .05 ml pooled broiler breeder chicken semen. The hens had an average fertility of 92.3% from 25 wks of age. All settable eggs laid during the 26 d study period

were identified by hen, individually weighed and placed in an incubator the same day they were laid. For the purposes of this experiment, eggs capable of being set included eggs with shell deformities, abnormal shapes or double yolked eggs. After 7 to 10 d of incubation under standard conditions, the eggs were broken out and scored macroscopically as fertile alive, fertile dead (early embryonic death) or clear (assumed infertile). The duration of fertility was defined as the number of days from the day after the second insemination to the last fertile egg before two consecutive infertile eggs. In order for a hen to be included in the data set she must have laid at least one fertile egg. Hens excluded from the first study period remained eligible to participate in the second study. Hens producing no eggs were culled from the experiment. As a result of these criteria, four R and five F hens were removed from the data set in Study 1 and three R and six F hens were removed from the data set in Study 2.

One-way analyses of variance were computed within each study period using the General Linear Models procedure of SAS (SAS Institute, 1992) to determine differences between treatments (F or R). Pearson Correlation coefficients were computed between mean hen BW, BW gain, settable egg production, average egg weight and duration of fertility across treatments within each study ($n_1 = 51$, $n_2 = 51$). Settable egg production was expressed as a percentage of hen day settable egg production over 26 d. Significance was assessed at $P < 0.05$.

2.3 RESULTS AND DISCUSSION

The mean BW of the R and F hens were significantly different within each study period (Table 2-1 and Figure 2-1). The high variance associated with the average gains over each study period was related to the fact that some hens lost BW during the study. An equal number of R and F hens in each study lost BW despite the fact that the F hens had *ad-libitum* access to feed. A greater number of hens lost weight in Study 2 than in Study 1 (11 hens for Study 2 versus 6 hens for Study 1). As seen in Table 2-1, hen day settable egg production was not different between treatments in either Study 1 (F=52.6%, R=60.2%; P=0.095) or in Study 2 (F=49.2%, R=56.1%; P=0.128). Average egg weight was also not significantly different between feed allocation treatments in either Study 1 (F=71.0 g, R=69.1 g; P=0.063) or Study 2

(F=71.2 g, R=69.2 g; P=0.057) (Table 1-1). There were no significant differences between treatments in the percent of fertile eggs laid, the percent abnormal eggs (shell deformities or shape deformities) or the percent of double yolked eggs in either of the 26 d study periods.

In Study 1 there was no difference in the duration of fertility between the R (12.7 d) and the F (12.7 d) treatments. In Study 2 there was a significant reduction in the duration of fertility of the F hens (10.0 d) compared to the R hens (12.7 d) by 2.7 d (Table 2-1). This suggestes that the additional weight gain of the F hens during Study 2 impaired their ability to maintain fertility. Fertility problems can occur at three levels; sperm storage capacity, sperm transportation and oocyte health. It is unclear why the F hens in Study 2 had a reduced duration of fertility. It is important to note that since all fertility evaluations were conducted macroscopically, some very early dead embryos may have been mistakenly identified as infertile.

There were significant correlations between the following variables for both study periods: average hen weight and settable egg production (r = - 0.425 for Study 1, r = - 0.421 for Study 2), and duration of fertility and settable egg production (r = 0.293 for Study 1, r = 0.369 for Study 2). These findings support the observations of Beaumont *et al.* (1992) who suggest that there is a correlation between laying rate and duration of fertility in broiler breeder hens. The correlation of average hen BW and average egg weight (r = .306) was significant for Study 1 and the correlation of average hen weight with duration of fertility was significant in Study 2 (r = - .280).

The longest period post insemination in which a hen laid a fertile egg was 22 d. This egg was preceded with four infertile eggs. It was not uncommon for a hen to lay one or more infertile eggs within a clutch of fertile eggs. Duration of fertility estimates would have been longer had the duration of fertility been defined as the number of days to the last fertile egg and not to the last fertile egg before two infertile eggs.

This experiment provides further support for the negative influence of increased BW on the duration of fertility in broiler breeder hens. It also suggests, however, that extreme differences in BW are required in order to affect the duration of fertility. Considering that only 1-2% of inseminated sperm actually remain in the oviduct (Bakst *et al.*, 1994), and that the number of sperm residing in the sperm

storage tubules is directly proportional to the duration of fertility (Brillard, 1993), efforts focused at increasing or maintaining the number of sperm remaining in the oviduct may improve the duration of fertility. Given that the duration of fertility of the F hens in Study 2 was 10.0 d, this experiment appears to indicate that BW has little practical effect on the duration of fertility when inseminations are conducted weekly. However, the effects of *ad-libitum* feeding may require more than 8 weeks to have an effect. If so, BW may have a practical effect on the duration of fertility even with weekly inseminations. It is not known with certainty how often individual hens are mated in floor housed stocks. However, if the reduced duration of fertility in the F hens in Study 2 was due to a reduced number of sperm residing in the sperm storage tubules of the uterovaginal junction, this could affect the likelihood of fertilization regardless of insemination frequency.

TABLE 2-1. Means (± SD) of bird BW, BW gain, production level, settable egg weight and duration of fertility measured by treatment for each study period

Study	Treatment	Number of hens	Mean BW (g)	BW gain (g) [1]	Egg production (%)	Average egg weight (g)	Duration of fertility (d)
1 (56 - 60 wks)	Restricted	26	3459 ± 188[b]	101 ± 81	60.2 ± 10.7	69.1 ± 3.1	12.7 ± 2.9
	Full Fed	25	4261 ± 347[a]	154 ± 217	52.6 ± 20.0	71.0 ± 4.1	12.7 ± 3.1
2 (60 - 64 wks)	Restricted	27	3565 ± 197[b]	76 ± 102	56.1 ± 12.9	69.2 ± 3.3	12.7 ± 3.3[b]
	Full Fed	24	4448 ± 403[a]	116 ± 193	49.2 ± 18.8	71.2 ± 4.1	10.0 ± 4.6[a]

[1] BW gain = BW at end of study - BW at start of study.
[a,b] Means within a study with different superscripts are significantly different ($P<0.05$).

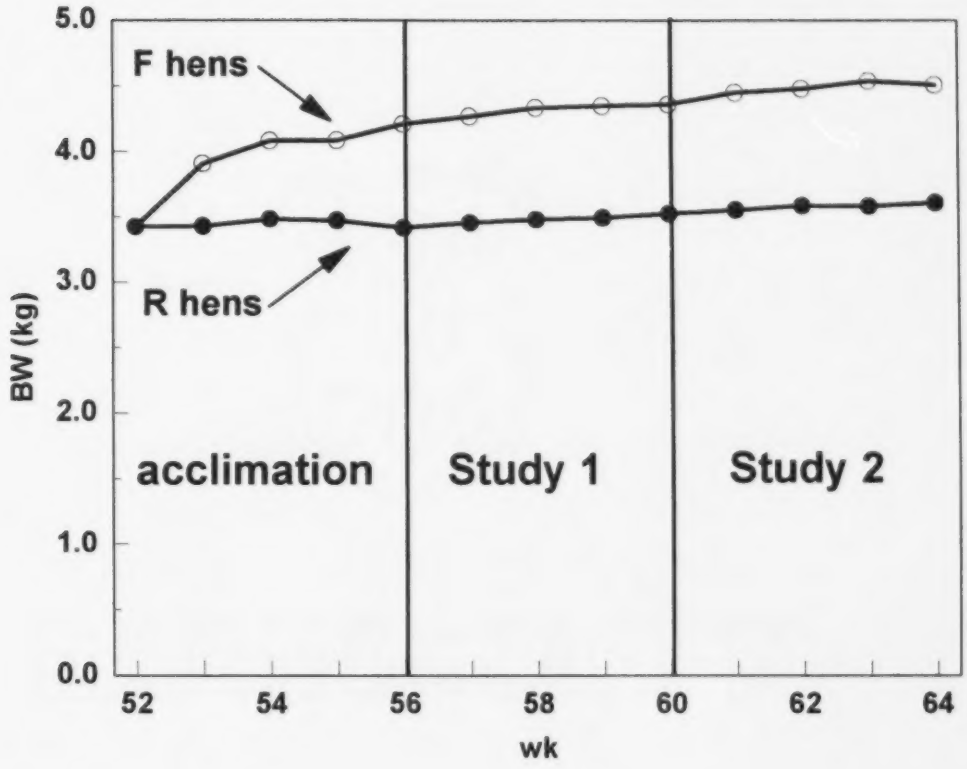

FIGURE 2-1. Body weight curves of the *ad-libitum* fed or F treatment hens (open circles) and the restricted fed or R treatment hens (solid circles) over the acclimation and both study periods.

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3. EFFECT OF TIME OF WEIGHING ON ESTIMATES OF FLOCK BODY WEIGHT AND AND BODY WEIGHT UNIFORMITY IN BROILER BREEDER PULLETS [1]

3.1 INTRODUCTION

Broiler breeder pullets are routinely feed restricted during rearing and breeding in order to limit BW gains, maximize egg production, and avoid problems due to excess weight (Yu *et al.*, 1992a). Feed restriction during the rearing period helps to maximize settable egg production, improve production persistency and maintain egg quality during the breeding period (Yu *et al.*, 1992b). A highly uniform flock is easier to manage since a large percentage of the birds will have common nutritional requirements throughout the rearing and breeding periods (Anonymous, 1994). A highly uniform flock of pullets should also respond to photostimulation in a similar manner, reaching sexual maturity within a narrow range of time. Although primary breeders recommend some form of feed restriction during both the rearing and breeding periods to control BW, few are specific about what time of day is best to weigh the birds. It has been shown that the time of weighing is an important source of error when estimating live weight gain in broiler breeder pullets (Fattori *et al.*, 1992). Fattori *et al.* (1992) sampled 8 and 10 wk old broiler breeder pullets on the non-feed day of a skip-a-day feeding program. While Fattori *et al* only weighed pullets on the non-feed day, body weight estimates taken on feed days would be of interest because some flock managers may be comparing weights of pullets sampled on feed and non-feed days. The objectives of this study were: 1) to determine if the time of weighing has a significant effect on observed mean BW and estimations of BW uniformity in 11 wk broiler breeder pullets, and; 2) to determine if BW estimates of the heaviest and lightest weight pullets in a flock respond to different weighing times in a similar manner to the flock mean.

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[1] A version of this chapter has been accepted for publication (Goerzen, P. R., P. Garvey, S. McDonald, and F. E. Robinson, 1996. Effect of time of weighing on estimates of flock body weight and body weight uniformity in broiler breeder pullets. J. Appl. Poultry Res. 5:xxx-xxx).

3.2 MATERIALS AND METHODS

One hundred and fifty seven Shaver Starbro[2] broiler breeder pullets were divided into three floor pens (1.8 m X 4.4 m) of 52 or 53 birds each. A skip-a-day feed restriction program was initiated at 3 wk of age. All pullets were individually wingbanded at 4 wk of age. The pullets were fed a standard broiler breeder grower diet (CP = 15%, ME = 2700 kcal/kg) as recommended by the breeder. Water was provided *ad-libitum*. All birds were reared according to the recommended breeder BW targets. Each pen contained two large pan feeders and two large cup drinkers. All birds in a pen had ample space to feed at the same time. The lighting regimen was 8 h of light per day provided from 8:00 to 16:00 h. Three 2-day replications were completed. Each replication consisted of a non-feed day followed by a feed day. The pullets were 10 to 11 wk old during the three replications. This age was chosen because the pullets still had ample space to feed at the same time. It was considered to be important to ensure that all pullets had equal access to feed so not to confound the BW or uniformity estimates with unequal feeding durations. Feed allocation varied slightly between the three pens (60-63 g/bird/day). Feeding commenced at 8:15 h on feed days. In each of the three replications, on both days the birds were weighed at 9:15 h and at 14:30 h. The birds were weighed while standing in a small pail on a platform scale. On feed days the birds were allowed to eat for 1 h, after which time the feeders were raised in all three pens. All birds were allowed to resume feeding after all three pens were weighed. Feed was completely consumed by the afternoon weighing. Within each replication, each bird was weighed four times in the following sequence: 1) in the morning of the non-feed day, 2) the afternoon of the non-feed day, 3) the morning of the feed day, and 4) the afternoon of the feed day. Since all weights were recorded by wingband, the heaviest and lowest weight pullets in each pen could be identified. The three heaviest and the three lowest weight pullets in each pen were tracked throughout the 6-day study. Body weight uniformity was estimated by determining the percentage of birds that were within $\pm$ 10% or 15% of the mean BW for each weighing time.

The data were analysed by analysis of variance (SAS Institute, 1992). The data were sorted by

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[2]Shaver Poultry Breeding Farms Ltd., Cambridge, Ontario, Canada N1R 5V9

replication and the variables (mean weight and uniformity) tested against the main effects (time, day, time x day). Mean differences between the interactions were assessed using Duncan's multiple range test. Statistical significance was defined as $P<.05$. There was no effect of pen on any of the parameters measured so data of all three pens were pooled (n = 157 birds). The BW measurements on the three heaviest and three lowest weight pullets in each pen were also pooled as two groups of nine birds each.

3.3 RESULTS AND DISCUSSION

Estimates of BW differed significantly by day, time and day X time in each of the three replications. The pullets were consistently and significantly heaviest on the afternoon of feed days and lightest in the afternoon of non-feed days within each of the three replications. Within each replication, recorded mean BW was 11.4% to 12.1% heavier in the afternoon of feed days than on the afternoon of non-feed days (Table 3-1 and Figure 3-1). The mean BW was significantly different between the AM and the PM weighings on both feed and non-feed days in all three replications. This would indicate that in addition to the day that the birds were weighed (feed or non-feed), the time within that day had a significant effect on the recorded BW. Pullets were lightest in BW on the afternnon of non-feed days. Thus, in order to measure pullet BW and not gut fill, birds should be weighed in the afternoon of non-feed days. These conclusions support earlier work by Fattori *et al.* (1992) who found that time of weighing is an important source of error when estimating live weight gain in broiler breeder pullets.

As previously mentioned, the nine heaviest and the nine lowest weight pullets were tracked throughout the study. Regardless of weighing time, the heaviest pullets remained the heaviest and the lightest weight pullets remained the lightest. The continuous BW growth curves for these nine heaviest and nine lightest weight pullets follow the same trend as the flock mean growth curve indicating that regardless of BW, all pullets respond to different times of weighting in a similar manner (Figure 3-1). There was not the same level of significant difference between body weight measurements within a replication because of the limited sample size. These findings may be of interest to poultry researchers or primary breeders who select pullets based on BW.

While there were no significant differences in the uniformity estimates for any of the weighing times, uniformities were consistently numerically higher on the feed days. This may be due to birds having a crop full of feed on the feed days. This would increase the number of birds with a BW within ± 10% or 15% of the mean BW by increasing the overall mean BW while maintaining the same numeric range in individual pullet BW. Uniformity estimates at 10% were in the range of 51-58% while uniformity estimates at 15% were in the range of 70-76%.

Weekly BW measurements taken at different times of the day are not comparable and will not give an accurate representation of pullet growth. The consequences of not weighing broiler breeder pullets in a consistent manner would be incorrect weekly feed allocations possibly resulting in an overweight or underweight flock. Broiler breeder pullets should be weighed in the afternoon of non-feed days when reared under a skip-a-day feed restriction program in order to ensure accurate BW estimations.

TABLE 3-1. Effect of time of weighing on mean BW and uniformity estimates for the flock mean, and mean BW for the nine heaviest pullets and the nine lowest weight pullets for each of the three replications over the study period

Replication	Day of Week	Type of Day	Time of Day	Mean BW	Uniformity at ± 10%[1]	Uniformity at ± 15%[1]	Lowest BW	Heaviest BW
1	Monday	non-feed	AM	977.1 [b]	53.5 [a]	76.4 [a]	749.8 [b]	1216.3 [a]
1	Monday	non-feed	PM	953.5 [c]	53.5 [a]	73.8 [a]	716.5 [b]	1187.8 [a]
1	Tuesday	feed	AM	987.5 [b]	58.6 [a]	73.9 [a]	747.1 [b]	1230.6 [a]
1	Tuesday	feed	PM	1062.6 [a]	55.4 [a]	72.6 [a]	806.8 [a]	1234.7 [a]
2	Wednesday	non-feed	AM	1006.5 [k]	55.4 [a]	72.6 [a]	758.4 [l]	1250.7 [jk]
2	Wednesday	non-feed	PM	981.5 [l]	53.5 [a]	70.0 [a]	733.5 [m]	1223.2 [k]
2	Thursday	feed	AM	1030.2 [k]	58.6 [a]	73.9 [a]	775.9 [k]	1284.6 [jk]
2	Thursday	feed	PM	1100.0 [j]	56.0 [a]	73.9 [a]	829.8 [j]	1369.6 [j]
3	Friday	non-feed	AM	1038.2 [y]	54.1 [a]	73.2 [a]	789.7 [w]	1297.0 [w]
3	Friday	non-feed	PM	1012.8 [z]	51.6 [a]	71.9 [a]	805.9 [w]	1252.8 [x]
3	Saturday	feed	AM	1061.1 [x]	55.4 [a]	73.9 [a]	803.3 [w]	1318.0 [w]
3	Saturday	feed	PM	1131.0 [w]	56.7 [a]	76.4 [a]	863.8 [w]	1410.9 [w]

[abc] Mean BW values (compared within a replication) with different letters are significantly different (P<.05)
[1]Percentage of birds within ± 10% or ± 15% of the flock mean BW.

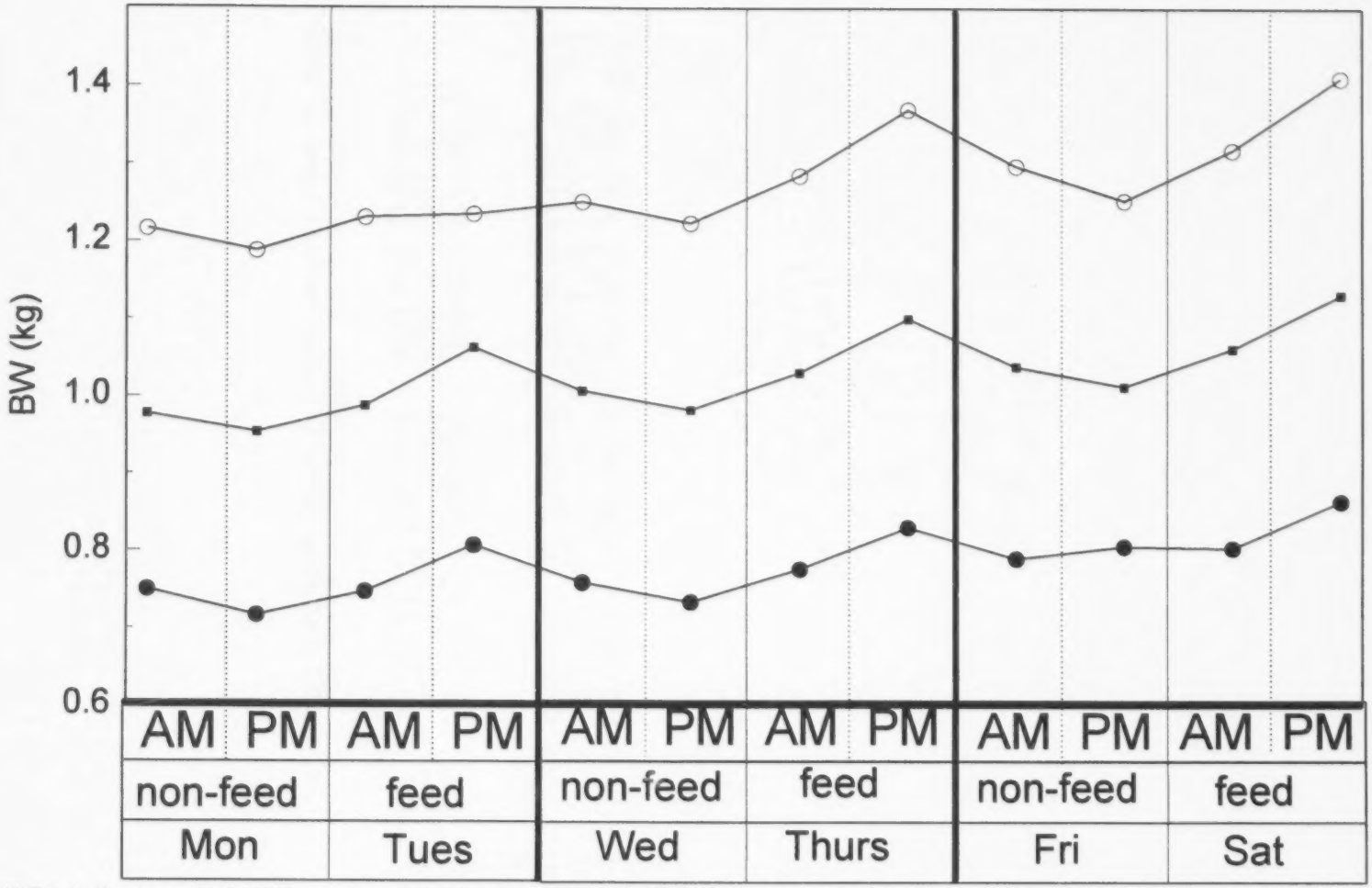

FIGURE 3-1. Continuous pullet BW growth curve for the nine heaviest pullets (open circles), the flock mean (squares) and the nine lowest weight pullets (closed circles) for each of the three replications over the study period (rep 1 = Mon-Tues, rep 2 = Wed-Thurs, rep 3 = Fri-Sat).

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4. THE EFFECT OF SMALL DIFFERENCES IN GROWTH CURVE AND AGE AT PHOTOSTIMULATION IN FEMALE BROILER BREEDERS. 1. CARCASS TRAITS AND OVARIAN MORPHOLOGY AT PHOTOSTIMULATION AND SEXUAL MATURITY

4.1 INTRODUCTION

Feed restriction programs for broiler breeders are necessary to control BW (Yu *et al.*, 1992a) and ovarian follicular development (Hocking *et al.*, 1989) in order to ensure adequate reproductive function (Robinson *et al.*, 1993). Feed restriction delays age at sexual maturity (Robbins *et al.*, 1986; Yu *et al.*, 1992b) possibly by delaying maturation of the hypothalamic-anterior pituitary axis (Yu *et al.*, 1992b), or by later attainment of a threshold BW (Brody *et al.*, 1980; Dunnington *et al.*, 1984), lean body mass (Soller *et al.*, 1984) or body fat (Bornstein *et al.*, 1984) for sexual maturation. While the effect of *ad-libitum* versus feed restriction programs on attainment of sexual maturation and carcass traits at sexual maturation have been established, the effect of small differences in feed restriction or BW targets similar to those seen in the poultry industry, have not been as extensively investigated.

Fattori *et al.* (1993) investigated the effect of small differences in BW target created by allocated feed such that all treatments received equivalent amounts of all required nutrients except energy. They found a dose response of reduced days to sexual maturity (defined as age at 50% production) with increasing BW and concluded that feed restriction delayed the development of attributes associated with sexual maturity without altering their physiological values. Robinson and Robinson (1991) reported a proportional delay in age at sexual maturity with increasing BW among birds differing in 21 wk BW. Wilson *et al.* (1995) showed that birds grown on a early slow rearing curve had less carcass protein and carcass ash at 25 wk than birds grown on a linear or early fast growth curve in spite of the fact that all birds were the same BW at 25 wk of age.

Robinson *et al.* (1995) investigated the interaction of photoperiod at photostimulation and rate of feed allocation from 20 to 25 wk of age on carcass traits and ovarian morphology at sexual maturity. They

found that a single step increase in photoperiod at photostimulation increased ovary weight at sexual maturity and fast feed allocation increased large yolky follicular development whereas age, BW, and abdominal fatpad weight at sexual maturity were not different. Wautier (1994) photostimulated broiler breeder pullets from 120 to 160 d of age and found that as age at photostimulation increased, the interval between photostimulation and sexual maturity decreased. Pullets photostimulated earlier had lower levels of carcass fat at photostimulation, yet all groups of birds had similar levels of carcass fat at sexual maturity. Attainment of sexual maturity after photostimulation may have been delayed by the higher amounts of carcass fat gain required in the birds photostimulated earlier.

The objectives of this experiment were to determine the effect of small differences in BW and different ages at photostimulation on carcass traits and ovarian morphology at the time of photostimulation and at the time of sexual maturity in modern commercial broiler breeder females. The effect of the treatments on the pullet's ability to respond to increasing day length, characterization of the onset of sexual maturity, and the effect of small differences in feed allocation on ovarian morphology were of primary interest.

4.2 MATERIALS AND METHODS

4.2.1 Stocks and Management Before 18 wk of Age

Four hundred and fifty day old Shaver Starbro[1] broiler breeder pullets were randomly distributed, 50 per pen, to one of nine floor pens (1.8 m X 4.4 m) in a light-tight facility. All birds were fed *ad-libitum* to 2 wk of age at which time a skip-a-day feed restriction program was initiated. Water was provided *ad-libitum*. Each pen contained three pan feeders (diameter = 35.0 cm) and two cup drinkers (diameter = 17.0 cm). All birds had adequate space to feed at the same time. One hundred and fifty birds were grown to breeder recommended target BW (STANDARD), 150 birds were grown on a lighter growth curve (LOW) and 150 birds were grown on a heavier growth curve (HIGH) (Figure 4-1). Feed allocations were made in

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increments of 3 g / bird / d before 18 wk of age and if necessary multiple feed allocations were made each wk. Actual feed allocations at the beginning of each week are shown in Table 4-1. The three growth curves were designed so that at 20 wk of age the LOW and HIGH birds would be 150 g lighter or heavier respectively than the STANDARD birds. Differences in BW were maintained through to processing. Feed allocations were adjusted for each treatment beginning at 3 wk of age in order to create the three growth curves. All birds were fed pre-weighed amounts of feed every second day on a per pen basis between 3 and 18 wk of age. Birds were fed at 0800 h. Birds were individually weighed weekly in the afternoon on wk 1 and wk 2, and weekly at either a 6 or a 7 d interval on the afternoon of the non-feed day from 3 to 17 wk of age in order to calculate flock BW uniformity. Body weight uniformity was expressed as the coefficient of variation of BW within each pen. All pullets were wing-banded at 4 wk of age. The chickens were fed a starter diet from 0 to 3 wk of age, a grower diet from 3 to 20 wk of age, and a layer diet from 20 wk of age to processing, as recommended by the breeder(Table 4-2). All diets were fed in a mash form. The pullets received 24 h of light (24L:0D) on day 1, after which the lighting regimen was 8 h of light from 0800 to 1600 h per day (8L:16D) until photostimulation.

4.2.2 Management After 18 wk of Age

At 18 wk of age, the 116 birds on each growth curve that were closest to their target BW were designated to be used in the remainder of the trial. These birds were assigned a photostimulation age of either 19 wk of age (19WK) or 21 wk of age (21WK). The 116 birds from each growth curve were individually caged (51.0 cm x 45.7 cm) and from this time were fed individually on a daily basis. The experimental design consisted of a 3 by 2 factorial design with the main effects being growth curve (STANDARD, LOW or HIGH) and photostimulation age (19WK or 21WK). The main effect of growth curve was assigned at hatching and the main effect of photostimulation age was assigned at 18 wk of age. There were 58 birds in each of the six treatment combinations (LOW19, STANDARD19, HIGH19, LOW21, STANDARD21, and HIGH21). The birds were assigned to one of three groups and subsampled at various times for study of carcass composition and ovarian morphology. Twelve birds for each treatment combination were assigned to the A-Group and were processed at photostimulation. Ten birds

from each treatment combination were assigned to the B-Group; blood samples were taken weekly from 19 wk of age and the birds were processed the day after their first egg. The remaining 36 birds for each treatment combination were assigned to the C-Group and maintained to assess individual egg production until 61 wk of age when they were processed (data presented in Chapter 5).

After 18 wk of age, all birds were housed in the same light tight room. A light impermeable polyethylene wall with air recirculation ducts enabled the use of two photostimulatory programs within one room. At the time of photostimulation, the day length was increased in both rooms from 8L:16D to 11L:13D, followed by a 1 h increase in light per week to 15L:9D. The lights came on at 0600 h. The temperature within each room was maintained between 16 and 21 C. The wall was removed at 25 wk when both the 19WK and the 21WK lighting programs were the same.

All birds within a treatment were fed according to their BW target and stage of productivity. Feed allocations were made in increments of 5 g / bird / d or less after 18 wk of age. When necessary, multiple changes in feed allocations were made each week. Actual feed allocation at the beginning of each week are shown in Table 4-3. All birds were fed daily on an individual bird basis from 18 wk of age until processing. Feed was provided at 0730 h after 18 wk of age. Feed was weighed into individual cups using an automated feed allocation system (Feddes *et al.*, 1995). After 18 wk of age, weekly individual BW were recorded in the morning prior to feeding. The experimental protocol was approved by the Faculty of Agriculture, Forestry and Home Economics, of the University of Alberta's Faculty Animal Policy and Welfare Committee.

4.2.3 Carcass Examinations

Birds were killed by cervical dislocation at 0730 h, prior to when they would have normally been fed. After being weighed, the birds were dissected to determine the weight of the breast muscle (*pectoralis major and minor)*, the abdominal fatpad (including fat adhering to the gizzard), the oviduct, the ovary, and the liver. These component weights were expressed as the actual weight of the component and as a percentage of live bird BW at processing.

The ovary was dissected and the number of large yellow follicles (LYF) (diameter > 10 mm) were

counted and individually weighed. The number of small yellow follicles (SYF) (diameter < 10 mm and > 5 mm) were counted and the weight of the stroma (the ovary less the LYF) recorded. Atretic follicles were visually identified based on their irregular and / or shrunken appearance. Any incidence of atresia among the SYF or LYF was noted as follicular atresia. The number of follicles within a pair or triplicate of follicles within 1 g of each other were counted and divided by the total number of LYF in order to determine the percent of LYF within 1 g. This was done in order to estimate the proportion of LYF that were similar in size to their neighbouring follicle(s) in the LYF hierarchy.

Care was taken to determine the position of the egg in the oviduct in order to determine the stage of egg formation. If the hen had a shelless egg in the oviduct, she was considered to have already ovulated that day. If the hen had not yet ovulated that day, as indicated by a shelled egg or no egg in the oviduct, the F1 follicle weight was subtracted from the total ovary weight or the F1 was not used in the percent of LYF within 1 g determination. Ovary weights and the percent of LYF within 1 g were standardized in this manner in order to take into account birds which may have ovulated shortly prior to processing. Such hens would have a lower ovary weight or fewer larger size LYF because they would not have a follicle in the F1 stage of development as would a hen which had not ovulated.

The length of the left shank (length of the tibiotarsus measured from the top of the hock joint to beside the footpad between the second and third toe) was also recorded. In the A-Group and B-Group birds, all of the carcass components with the exception of the liver were placed back into the carcass and frozen for subsequent analysis. Whole body composition was determined on an individual bird basis following the procedure described by Yu *et al.* (1990). In brief, each carcass, excluding the liver, was autoclaved for 3.5 h and homogenized in an industrial blender. A 500 ml subsample of each bird homogenized was freeze dried and ground in a household blender. Portions of the freeze dried sample were analysed in duplicate for petroleum ether-extractable fat, dry matter, crude protein, and ash content (Association of Official Analytical Chemists, 1980). The livers were freeze dried, ground in a household blender, and the total lipid content determined by petroleum ether extraction. The allowable difference between duplicates was 2% for petroleum ether extractable carcass lipid, carcass dry matter, carcass crude protein and petroleum ether extractable liver lipid, and 5% for carcass ash. Samples not meeting these

criteria were reanalysed. Carcass water, protein, fat and ash content were expressed as absolute weight as well as a percentage of live bird BW at the time of processing.

Ten mL of blood were collected weekly from each B-Group bird by brachio-venipuncture using an EDTA-primed vacuum blood collection tube with a 21 gauge needle. The blood was centrifuged at 1500 rpm for 15 min at 3 C. Plasma was stored at -30 C for subsequent RIA[2] determination of plasma estradiol-17β concentration. Parallelism in the RIA was determined by measuring the estradiol-17β concentration in different volumes of a plasma sample. The concentration of estradiol-17β was (mean ± SEM) 31 ± 3.0, 101.8 ± 6.8, 247.6 ± 8.4, and 599.5 ± 14.0 pg/ml, for 50, 100, 200 and 400 μL of plasma sample. Two hundred μL of each plasma sample was analysed in duplicate. The allowable percent difference between duplicates was 5%. The samples were analysed in four assays. The inter-assay coefficient of variation was 3.15% and the intra-assay coefficient of variation was 5.24%. The sensitivity of the assay was 1.5 pg/ml. The antiserum was highly specific for estradiol-17β with a relatively low cross reactivity to other naturally occurring steroids in the plasma sample as stated by the manufacturer. All tested compounds had a cross reactivity less than 1% with the exception of *d*-Equilenin (4.4%), estrone (10%), and estrone-β-D-glucuronide (1.8%).

4.2.4 Statistical Analyses

Data were subject to a two-way analysis of variance with sources of variation of growth curve, photostimulation age, and the interaction of growth curve x photostimulation age. When significant differences were determined for growth curve the comparisons were made among the growth curve least squares-means using Fisher's protected least significant difference procedure. If either or both of the main effects of growth curve or photostimulation age were significant, comparisons were made among the six growth curve x photostimulation age least-squares means using the least significant difference procedure. For consistency of presentation the six growth curve x photostimulation age least-squares means are presented for all variables. For all variables except BW uniformity, the error variation consisted of the

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[2]Kit Number TKE25, Diagnostic Products Corp., Los Angeles, CA 90045-5597

variation between birds within growth curve x photostimulation age. The error variation for BW uniformity consisted of the variation between pens within the main effect of growth curve.

Pearson correlation coefficients of the interrelationships among individual traits were computed across birds within the A-Group and within the B-Group. Stepwise regression was used on the B-Group bird data set to evaluate the influence of age at sexual maturity on 15 variables measured at sexual maturity. The 15 variables were BW, breast muscle weight, abdominal fatpad weight, liver weight, grams of liver lipid, carcass water weight, carcass protein weight, carcass lipid weight, carcass ash weight, oviduct weight, ovary weight, stroma weight, number of SYF, number of LYF, and the percent of LYF within 1 g. Also, regression of carcass composition traits, expressed as absolute weights and percent weights, and ovarian morphology characteristics on the age at sexual maturity were computed.

The profiles of estradiol-17β over time were plotted for all birds within each of the three growth curves and also within each of the two photostimulation ages. Since the B-Group birds were blood sampled weekly until the first egg was laid, the number of observations per week declined with time. When there were less than six observations per main effect in any one week, that weekly measurement was deleted from the data set. Differences between profiles were determined using the Kolmogorov-Smirnov 2-sample test within the three growth curves, within the two photostimulation ages and within the six growth curve x photostimulation age combinations. Predictive values were computed by determining the polynomial power which gave a similar curve shape and significant R^2 value to that of the' LOESS' procedure of SAS. All calculations were done using SAS (SAS Institute, 1994). Significance was assessed at the $P < 0.05$ level.

4.3 RESULTS AND DISCUSSION

4.3.1 Pullet Growth

The BW growth curves in Figure 4-1 represent all birds up to 17 wk of age and only A-Group birds past 17 wk of age. The BW growth curves in Figure 4-2 represent all birds up to 17 wk of age and only the B-Group birds past 17 wk of age. Actual BW were very close to target BW. Weekly BW between

the three growth curves of the A-Group birds and the B-Group birds were different from each other from 10 wk of age through to processing.

Body weight uniformity was estimated for each weekly weighing as the coefficient of BW around the mean (Figure 4-3). The main effect of growth curve was only significant at wk 1, at which time the HIGH birds were more uniform in BW than the STANDARD birds. However, at this time all three treatments were receiving *ad-libitum* access to feed and no treatment effect had yet been applied. Weekly BW uniformities were not different from wk 2 through to wk 17. Error variation was high due to the small number of replicate measures and relatively small number of birds within one BW uniformity estimate. Fattori *et al.* (1991) also found no negative effect of increased feed restriction on BW uniformity expressed as the coefficient of variation of BW around the mean. Increasing severity of feed restriction may have had an adverse effect on BW uniformity if feeder space had been limited.

4.3.2 A-Group Birds - Processed at Photostimulation

The main effect of growth curve (Table 4-4) had a significant effect on shank length at photostimulation; the HIGH birds had a longer shank length (104.9 mm) than the LOW birds (103.1 mm). There was a positive correlation (r=0.438) between BW and shank length at the time of photostimulation. Fattori *et al.* (1993) found that at photostimulation, feed restriction to 8% below standard BW caused a 3.4 mm reduction in shank length (110.1 mm) compared to feed restriction to 8% above standard BW (113.5 mm). In the present study, the carcass ash weight was also different between the LOW birds (51.6 g), the STANDARD birds (57.4 g) and the HIGH birds (63.2 g). The birds grown on higher BW targets had greater skeletal growth that birds grown on lower BW targets.

At the time of photostimulation, the absolute weight of all carcass components were higher in the HIGH birds compared to the LOW birds with the exception of the oviduct weight (Table 4-4). The differences between carcass component weights were likely a factor of the 338 g difference in BW between the HIGH and the LOW birds. Fattori *et al.* (1993) found significant differences in oviduct weight at photostimulation between similar differences in BW to those used here. While the differences between BW were similar, the BW used by Fattori *et al.*(1993) were much higher. Early oviductal development

may be strain specific or it may be sensitive to BW differences above a threshold BW that was not achieved here. All absolute measures of carcass component weights were positively correlated with BW. Percent carcass water weight was the only variable that was negatively correlated with BW (r=-0.289). Previous experiments have shown that as birds grow and mature they gain higher proportions of protein and fat at the expense of carcass water (Wilson *et al.*, 1995). Percent carcass fat weight and percent abdominal fatpad weight were the only carcass traits expressed as percentages to increase in response to increasing BW (Table 4-4). At photostimulation, the HIGH birds had a higher carcass fat content and a greater abdominal fatpad weight on a percentage basis (7.24 %, 0.53 %) than the LOW birds (6.01 %, 0.29 %). Percentage abdominal fatpad weight (r=0.408) and percentage carcass lipid weight (r=0.624) were also correlated to BW. Fattori *et al.* (1993) also found abdominal fatpad weight and percentage fatpad weight to increase proportionally with increasing BW target. Considering the requirement of percent carcass fat for the onset of sexual maturity (Bornstein *et al.*, 1984), the HIGH bird's attainment of sexual maturity may not be limited by carcass fat stores to the same degree as the LOW birds, so the HIGH birds would be expected to reach sexual maturity at a younger age.

The main effect of photostimulation age was significant on a number of the parameters measured at the time of photostimulation (Table 4-5). The BW of the 19 wk birds (1700 g) was lower than the 21 WK birds (1910 g). Shank length was not different between the two ages at photostimulation. However, absolute carcass ash weight was higher at 21 wk of age indicating a larger skeletal mass than at 19 wk of age. Lien *et al.* (Dept. Of Poultry Science, Auburn University, Auburn, Alabama, 36849-5416, personal communication) found no difference in shank length at photostimulation between birds photostimulated at 19 wk of age and at 21 wk of age. However, keel length increased from 19 to 21 wk of age suggesting that skeletal growth, as was shown in the present trial, was occurring in this time in the absence of a photostimulatory cue. Shank length may not be a very sensitive indicator of skeletal development. Skeletal growth may be better expressed by weekly measurements of frame size on individual birds. This may enable the detection of small changes and differences in skeletal growth.

Percent carcass protein weight and absolute carcass protein weight were greater in the birds photostimulated at 21 wk of age (21.00%, 389.0 g) than in the birds photostimulated at 19 wk of age

(19.42%, 319.5 g). This would indicate that significant lean muscle deposition or "fleshing" was occurring in this interval of time. This is in contrast to the data of Wautier (1994) who reported no differences in percent carcass protein at photostimulation ages ranging from 17 to 23 wk. The difference in protein deposition from 19 to 21 wk of age does not appear to be a factor of BW as there was no difference in percent carcass protein weight between the three growth curves. In addition, there was no correlation between BW and percent carcass protein weight at photostimulation. However, this carcass protein deposition was not reflected in the percent breast muscle weight (19WK = 15.58%, 21WK = 15.56%). Previous trials at the University of Alberta have established that carcass protein fluctuates very little between photostimulation at 20 wk of age and sexual maturity in feed restricted broiler breeders (Robinson, AFNS, University of Alberta, Edmonton, Alberta, T6G 2P5, personal communication). Birds photostimulated early may still be partitioning higher proportions of energy into lean tissue growth at the time of photostimulation than birds photostimulated later.

The oviduct more than doubled in weight on a percent and an absolute basis from 19 wk of age (0.018%, 0.30 g) to 21 wk of age (0.042%, 0.82 g). The percent and absolute weights of the ovary, the abdominal fatpad and liver lipid were not different between the two photostimulation ages. Percent ($r=0.294$) and absolute ($r=0.376$) oviduct weights were also positively correlated with BW. The percent liver weight and the percent liver lipid content were higher in the 19WK birds (1.99%, 0.076%) than the 21WK birds (1.79%, 0.066%). Absolute values of liver weight and liver lipid weight suggest that liver growth and lipid accumulation slowed some time prior to 19 wk of age. The absolute liver weight and the absolute liver lipid weight were not different between photostimulation ages (Table 4-5). Liver size and liver lipid content can be used as indicators of sexual maturity considering the impact of estradiol-17β on hepatic lipogenesis and the role of the liver in vitellogenesis (Redshaw and Follet, 1972). The lack of ovarian growth, liver growth and liver lipid accumulation from 19 to 21 wk of age does not correspond with the development of the oviduct in the same period of time as they are all stimulated by estradiol-17β. Early development of the oviduct in the absence of a photostimulatory cue has been shown by others (Wautier, 1994). Oviductal development may be very sensitive to early small increases in ovarian estradiol-17β.

The LOW21, STANDARD21, and HIGH21 birds had similar levels of percent carcass fat and absolute carcass fat (Table 4-6). Among the birds photostimulated at 19 wk of age, the HIGH19 birds had higher levels of percent and absolute carcass fat weight and abdominal fatpad weight than the LOW19 birds. This would suggest that when photostimulated, the 19WK birds would be more likely to respond to the cue in a nonuniform manner compared to the 21WK birds. The birds photostimulated at 21 wk of age would presumably meet their threshold requirements for carcass fat within a smaller margin of time regardless of their BW target. The HIGH19 birds had similar levels of BW, percent carcass fat weight, and percent carcass protein weight as the 21WK birds. The rate of response of the HIGH19 birds to the earlier photostimulatory cue may be similar to the rate of response of the LOW21 or STANDARD21 bird to the later photostimulatory cue.

The range in BW seen here likely reflect those within one flock under commercial conditions. The carcass data suggests that birds photostimulated early (19WK) may not be ready to respond to the photostimulatory cue in as uniform a manner as those birds photostimulated later (21WK). In addition, birds grown on lower BW targets (LOW) have lower skeletal mass and have lower levels of percent and absolute carcass fat than birds grown on higher BW targets (HIGH). During the period from 19 to 21 wk of age in the absence of a photostimulatory cue, birds are depositing significant amounts of lean tissue and are beginning oviductal development.

4.3.3 B-Group Birds - Processed at Sexual Maturity

The HIGH birds entered lay at a younger age (173.3 d) and at a heavier BW (2720 g) than the LOW birds (183.5d, 2585 g) and at similar levels to the STANDARD birds (178.0d, 2648 g) (Table 4-7). As previously demonstrated by Fattori *et al.* (1991) (r=0.84) and Pearson and Heron (1982) (r=0.88), BW was negatively correlated with age at sexual maturity (r=0.604). The lower correlation here was possibly due to a smaller BW range resulting in proportionally smaller differences in the age at sexual maturity. Shank length was not different between the growth curves (overall mean $\pm$ SEM = 107.2 $\pm$ 0.8 mm). The HIGH birds had lower percent carcass water weight (62.49%) than the STANDARD birds (63.42%) and the LOW birds (64.04%). Differences in percent carcass fat were not different (P=0.23) between the LOW

(10.18%), the STANDARD (10.36%) or the HIGH (11.22%) birds. In previous studies, carcass water was reduced with increases in carcass fat (Wilson *et al.*, 1995). The STANDARD birds had larger percent breast muscle weight (17.06%) than the HIGH birds (16.29%) and similar to that of the LOW birds (16.49%). The HIGH birds had heavier absolute carcass fat weight (292.0 g) than the LOW birds (254.2 g). There were no other significant effects of BW target on carcass traits suggesting a minimum threshold necessary for the onset of sexual maturity.

At sexual maturity, all absolute weights of carcass traits were positively correlated with BW. This is similar to what was observed in the birds processed at photostimulation (A-Group birds). Of the carcass traits expressed as a percent of BW, only the percent carcass lipid weight (r=0.259) and the percent abdominal fatpad weight (r=0.312) were positively correlated with BW. At sexual maturity, heavier birds had more fat and a higher proportion of fat. The LOW birds entered lay at a lighter BW and with a lower carcass fat weight than the HIGH birds. These results suggest that the LOW birds had lower thresholds of BW and absolute carcass fat weight for the onset of lay than the HIGH birds. Percent carcass fat was not different between the BW treatments at sexual maturity. Using a 1978 commercial broiler breeder, Bornstein *et al.* (1984) concluded that pullets require a threshold percent carcass fat in order to achieve sexual maturity. However, percent abdominal fatpad weight at sexual maturity were at least two and a half times greater than what was observed here. Selection for reduced fatness in the broiler may have reduced the threshold of percent carcass fat required for the onset of lay in the parent. Percent and absolute weights of carcass protein and carcass ash were also not different at sexual maturity, thus supporting conclusions by Soller *et al.* (1984) who stated that in White Rock broiler females there may be a lean body mass requirement independent of feeding treatment. There was no indication of a strong threshold for BW or age necessary for the onset of sexual maturity within the range of BW used here. This is in contrast to Brody *et al.* (1980) who suggested a minimum body weight requirement for the onset of lay in White Rock broiler females. Thresholds of BW and age may not play as strong a role in the restriction or release of sexual maturation as carcass fat, carcass protein and carcass ash content.

There was no difference (P=0.072) in the number of SYF in the ovary of the LOW birds (10.2), the STANDARD birds (11.0), or the HIGH birds (13.5) at sexual maturity. There was also no difference

(P=0.082) in the number of LYF in the ovary between the LOW birds (6.8), the STANDARD birds (7.0), or the HIGH birds (7.8) at sexual maturity. This is in contrast to Hocking (1993) who found that the number of LYF at sexual maturity was directly proportional to BW. These values of SYF and LYF numbers are within the range of those previously reported for feed restricted broiler breeder hens of both the same strain (Wautier, 1994; Robinson *et al.*, 1995) and of different broiler breeder strains (Yu *et al.*,1992b; Hocking 1993). There was however a higher percent of LYF within 1 g of each other in the HIGH birds (48.17%) compared to the STANDARD birds (29.46%) and the LOW birds (22.80%). This supports previous work indicating that small differences in feed allocation prior to sexual maturity can have a large effect on ovarian morphology at sexual maturity (Robinson *et al.*, 1995). The higher percent of LYF within 1 g in the HIGH birds may result in F2 follicles showing functional similarities (high progesterone production and low androstenedione production) to F1 follicles as shown with full fed broiler breeder hens (Yu *et al.*, 1992c). This may result in multiple ovulations occurring within one open period for luteinizing hormone release, leading to the production of double yolked eggs and defective eggs (Yu *et al.*, 1992b; Robinson *et al.*, 1993).

Six of the 60 B-Group birds exhibited evidence of follicular atresia at sexual maturity. While follicular atresia was not different between either the three growth curves or the two photostimulation ages, incidence of follicular atresia across all birds was positively correlated to BW at sexual maturity (r=0.298) and to age at sexual maturity (r=0.376). The incidence of atresia may be responsible for delaying the onset of sexual maturity. Six of the 60 birds processed at sexual maturity had evidence of internal ovulation, although there was no treatment effect.

The birds photostimulated at 19 wk of age entered lay 7.8 d before and at a BW of 134 g lower than the birds photostimulated at 21 wk of age (Table 4-8). The 21WK birds had a smaller percent breast muscle weight (16.35%) and a larger percent liver weight (1.86%) than the 19WK birds at sexual maturity (16.86% and 1.73% respectively). On an absolute basis the 21WK birds had a heavier carcass protein weight (19WK = 509.5 g, 21WK = 534.8 g), a heavier liver weight (19WK = 44.8 g, 21WK = 50.4 g) and a heavier oviduct weight (19WK = 62.4 g, 21WK = 69.4 g) than the 19WK birds. Absolute liver weight and ovary weight were also lower in the 19WK birds. Ovarian morphology parameters including number

of SYF, number of LYF, percent of LYF within 1 g, and ovary weight were not different between the two ages at photostimulation. Photostimulation age had an effect on age at sexual maturity and BW at sexual maturity but little effect on carcass traits and ovarian morphology at sexual maturity. Birds photostimulated at 19 wk of age appeared to have had lower requirements for BW and chronological age than birds photostimulated at 21 wk of age. As with the effect of growth curve, BW and age did not appear to be powerful thresholds restricting or releasing the onset of lay. The birds photostimulated at 19 wk of age had smaller livers at sexual maturity. These birds may have had an impaired ability to mobilize fat and deposit yolk into the rapidly developing follicles necessary for the rapid onset of high rates of lay.

The interaction means (Table 4-9) support previous observations made based on the main effects of growth curve and photostimulation age. All of the birds entered lay at the same BW with the exception of the HIGH21 birds. The HIGH21 birds entered lay at a higher BW (2816 g) than did the LOW19 birds (2536 g), the STANDARD19 birds (2592 g), the HIGH19 birds (2624 g), and the LOW21 birds (2635 g). With the exception of HIGH21 birds, which had higher absolute carcass protein weight, neither absolute or percent weights of carcass protein, carcass fat or carcass ash were different between the interaction groups. The percent carcass protein weight at sexual maturity for all interactions were within 0.45% of the birds processed at 21 wk of age (21WK A-Group birds). While there was significant protein deposition between 19 and 21 wk of age in the absence of a photostimulatory cue, proportionally no further lean tissue growth occurred from the time of photostimulation at 21 wk of age to sexual maturity. This supports previous work by Robinson (AFNS, University of Alberta, Edmonton, Alberta, T6G 2P5, personal communication). These results indicate that the birds photostimulated at 19 wk of age were partitioning higher proportions of energy into lean tissue growth during the time of rapid ovarian and oviductal development. This may have a negative effect on the 19WK bird's ability to quickly respond to the photostimulatory cue and initiate high rates of egg production.

The regression models from the stepwise regression calculation are shown below. Parameter coefficients preceding independent variables within the regression model indicate the change in the dependent variable age at sexual maturity (d) associated with the change of one unit of the independent variable holding all other variables in the model constant;

age at sexual maturity = 105.97 + 0.21(liver weight)+ 0.15(oviduct weight)
- 0.54(number of SYF) - 3.20(number of LYF) + 0.05(carcass water weight)
- 0.05(carcass protein weight) + 0.04(carcass lipid weight)
- 10.66 (proportion of LYF within 1 g) + 0.61(ovary weight), $R^2 = 0.710$

The carcass water weight was highly correlated with BW (r=0.926) and carcass water weight likely entered the model in place of BW. Follicular development and recruitment had a large impact on the age at sexual maturity. All other carcass traits appeared to be associated with a delay in sexual maturity with increased weight with the exception of carcass protein weight. There was also shown to be a negative correlation between BW and age at sexual maturity. These regression data suggest that close to the time of first egg, the limiting factor for the onset of lay may be the level of follicular development. The advanced age at sexual maturity seen in the HIGH birds may have been a direct result of the higher percent of LYF within 1 g. The incidence of follicular atresia was positively correlated to both BW at sexual maturity and to age at sexual maturity. Ovulation rate is the balance of atre and follicular recruitment (Gilbert *et al.* 1983). Our data suggests higher rates of follicular atresia prior to sexual maturity may limit the onset of lay.

The regression equations of carcass composition, expressed on an absolute weight basis and on a percent weight basis, and of ovarian morphology characteristics on age at sexual maturity were computed;

age at sexual maturity = 128.85 + 0.03(carcass protein weight) + 0.04(carcass lipid weight)
+ 0.27(carcass ash weight), $R^2 = 0.273$

age at sexual maturity = 173.61 - 0.73(percent carcass protein weight)
+ 0.92(percent carcass lipid weight) + 2.88(percent carcass ash weight), $R^2 = 0.040$

age at sexual maturity = 135.56 - 0.56 (number of SYF) - 3.67 (number of LYF)
- 7.15 (percent of LYF within 1 g) + 0.76 (ovary weight) + 0.54 (oviduct weight), $R^2 = 0.540$

Body weight was not included in the regression model because it was highly correlated with absolute weights of carcass traits. Initially, these data suggest that thresholds of carcass composition necessary for the onset of lay were best described as absolute weights and not as percentages of bird BW. However, increases in all carcass trait variables were associated with an increase in the age at sexual maturity with the exception of percent carcass protein and absolute carcass protein weight. In the present trial, percent carcass protein weight did not change from photostimulation at 21 wk of age to sexual maturity. The effect of carcass protein content on age at sexual maturity was not consistent. Carcass protein content likely had a minimal effect on the onset of sexual maturity, particularly in the birds photostimulated at 21 wk of age.

Unlike carcass fat content, carcass protein content did not change. While there appear to be thresholds of carcass traits for the onset of sexual maturity, carcass traits do not appear to impose a strong restriction on the onset of egg production. However, in support of previous conclusions, follicular recruitment and development were associated with a lower age at sexual maturity.

Plasma estradiol-17β profiles for each of the growth curves and photostimulation ages are shown in Figures 4-4 and 4-5. The only significant main effect was that of photostimulation age (Figure 4-4). The 19WK birds responded linearly to the photostimulatory cue, whereas the21WK birds maintained basal levels of estradiol-17β until the point of photostimulation at which time they responded with an increased rate of estradiol-17β production. The birds photostimulated later (21WK) were interpreted as being able to respond to the photostimulatory cue with a faster rate of maturation than the 19WK birds. The levels of estradiol-17β seen here at the time of first egg agree with published values (Johnson and van Tienhoven, 1980). There is very limited information on the level of estradiol-17β in the plasma prior to photostimulation and during the period from photostimulation to sexual maturity. Peterson and Webster (1974) showed that chicks had increasing levels of plasma estradiol-17β concentration from hatch to maximum levels 2 to 3 wk prior to sexual maturation. However, chicks were not subject to a controlled photostimulatory program. Estradiol-17β is produced in increasing amounts by the small pool of follicles in the developing ovary in response to increasing plasma LH levels which in turn are stimulated by increasing day length (Robinson and Etches, 1986). Thus, plasma estradiol-17β levels can be used as an indicator of the birds ability to respond to the photostimulatory cue. In the A-Group birds, there was no growth of the ovary, abdominal fatpad, liver or increase in liver lipid from 19 to 21 wk of age in the absence of photostimulatory cue. This supports findings presented here showing that in the absence of photostimulatory cue, the 21WK birds maintained low and constant levels of estradiol-17β. This also supports the statement that early oviductal development, as seen in the A-Group birds processed at photostimulation, may be very sensitive to early small increases in ovarian estradiol-17β.

At 27 wk of age the 21WK estradiol-17β levels were lower than at 26 wk. The data point at 27 wk is represented by six birds, five LOW21 and one STANDARD21. Three LOW21 birds had lower 27 wk estradiol-17β levels than their 26 wk levels and they entered lay on average 7 d after the other three

birds who increased in estradiol-17β levels from 26 to 27 wk of age. These three LOW21 birds appeared to be unable to maintain high levels of estradiol-17β production. It is unclear whether this was an effect of their lower BW or some threshold possibly required for steroidogenesis.

Thresholds of carcass composition necessary for the onset of sexual maturation independent of the differences in growth curve or photostimulation ages have been presented in this chapter. Percent carcass fat, percent carcass protein and percent carcass ash at sexual maturity were not different between the three growth curves or two photostimulation ages. The number of SYF, number of LYF and the percent LYF within 1 g limited the onset of sexual maturity. There may be two levels of thresholds required for the onset of lay. Thresholds of carcass traits necessary for sexual maturity may limit maturity of the hypothalamic-anterior pituitary axis (Yu *et al.*, 1992b). Ovarian recruitment and growth, as well as large increases in plasma estradiol-17β concentration, will not occur until the hypothalamic-anterior pituitary axis is mature. Birds that have met their carcass thresholds necessary for maturation of the hypothalamic-anterior pituitary axis may be dependent on attaining thresholds of ovarian development in order to achieve sexual maturity. After maturation of the hypothalamic-anterior pituitary axis, continued growth and development of carcass traits may have no effect on the onset of lay. The birds photostimulated at 21 wk of age appeared to have been able to respond to the photostimulatory cue at an increased rate of maturation than birds photostimulated at 19 wk of age. At the time of photostimulation they may have been closer to achieving thresholds of carcass traits necessary for the maturity of the hypothalamic-anterior pituitary axis. In future experiments it may be useful to blood sample and process birds at different ages in order to correlate maturity of the hypothalamic anterior-pituitary axis, indicated by estradiol-17β levels, with carcass traits.

TABLE 4-1. Feed allowances (g / bird / d) for the main effect of growth curve (LOW, STANDARD or HIGH) from 0 to 18 wk of age, birds were fed twice as much as the stated value shown every second day from 2 to 18 wk of age

	Growth Curve		
Age	LOW	STANDARD	HIGH
(wk)	(g per bird per day)		
0 to 1	*ad-libitum*	*ad-libitum*	*ad-libitum*
1 to 2	*ad-libitum*	*ad-libitum*	*ad-libitum*
2 to 3	29.7	29.3	29.7
3 to 4	29.7	30.0	30.7
4 to 5	32.6	32.9	33.6
5 to 6	36.1	36.5	37.1
6 to 7	40.1	40.4	41.1
7 to 8	44.1	44.4	45.1
8 to 9	47.9	48.4	49.1
9 to 10	52.1	53.7	55.8
10 to 11	55.0	60.0	62.8
11 to 12	55.0	63.3	68.7
12 to 13	56.4	65.8	71.8
13 to 14	57.1	66.5	73.6
14 to 15	57.9	67.0	74.4
15 to 16	58.9	67.8	75.3
16 to 17	61.7	70.3	78.0
17 to 18	64.7	73.3	81.0

Table 4-2. Composition and analyses of experimental diets

Ingredients and analyses	Starter (0 to 3 wk)	Grower (3 to 19 wk)	Layer (19 to 61 wk)
	(%)		
Ground wheat, Western	44.23	34.42	33.76
Ground corn	14.18	16.44	14.31
Ground oats, Ontario	5.00	12.50	10.00
Soybean meal (48% CP)	17.34	7.37	13.42
Ground barley, Ontario	5.00	10.00	15.00
Wheat shorts	7.50	15.00	1.29
Limestone	1.65	1.72	7.68
Dicalcium Phosphate	1.58	0.86	1.06
Choline Chloride premix[1]	0.50	0.50	0.50
Broiler premix[2]	0.50	0.50	
Layer premix[3]			0.50
Salt	0.35	0.33	0.28
L-Lysine HCL	0.03	0.16	0.03
DL Methionine	0.14	0.13	0.17
Tallow	2.00	0.07	2.00
Rumensin	0.08	0.05	0.00
Total	100.0	100.0	100.0
Calculated analyses [4]			
CP, %	18.05	14.98	15.49
ME, kcal/kg	2875	2706	2750
Ca, %	1.00	0.90	3.20
Total P, %	0.70	0.56	0.54
Lysine, %	0.90	0.75	0.75
Methionine, %	0.41	0.35	0.41

[1] Provided choline chloride at a level of 100 mg/kg in the diet.

[2] The broiler premix provided the following per kilogram of diet: vitamin A, 10,000 IU; vitamin D3, 2,500 IU; vitamin K, 2.0 mg; pantothenic acid, 14.0 mg; riboflavin, 5.0 mg; folacin, 0.8 mg; niacin, 65.0 mg; thiamine, 2.0 mg; pyridoxine, 4.0 mg; vitamin B12, 0.015 mg; biotin, 0.18 mg; vitamin E, 35 IU; iodine, 0.5 mg; maganese, 70.0 mg; copper, 8.5 mg; zinc, 80.0 mg; selenium, 0.1 mg; iron 100.0 mg.

[3] The layer premix provided the following per kilogram of diet: vitamin A, 12,000 IU; vitamin D3, 3,000 IU; vitamin K, 2.0 mg; pantothenic acid, 14.0 mg; riboflavin, 6.5 mg; folacin, 1.0 mg; niacin, 40.0 mg; thiamine, 3.3 mg; pyridoxine, 6.0 mg; vitamin B12, 0.02 mg; biotin, 0.20 mg; vitamin E, 40 IU; iodine, 0.5 mg; maganese, 75.0 mg; copper, 15.0 mg; zinc, 80.0 mg; selenium, 0.1 mg; iron 100.0 mg.

[4] According to NRC (1984) guidelines.

TABLE 4-3. Feed allowances of the six different growth curve x photostimulation age interactions (LOW19, STANDARD19, HIGH19, LOW21, STANDARD21 or HIGH21) from 18 wk of age to processing, all birds were individually caged and fed individually on a daily basis

	Growth Curve x Photostimulation Age					
Age	LOW19	STAND19	HIGH19	LOW21	STAND21	HIGH21
(wk)	(g per bird per d)					
18 to 19	67	76	85	67	76	85
19 to 20	70	79	88	70	79	88
20 to 21	73	82	91	73	82	91
21 to 22	78	85	94	78	85	94
22 to 23	87	93	102	87	93	100
23 to 24	96	102	111	96	102	109
24 to 25	105	111	120	105	111	118
25 to 26	114	120	129	114	120	127
26 to 27	126	132	141	123	129	136
27 to 28	132	138	147	129	135	142
28 to 29	138	144	153	135	141	148
29 to 30	147	153	162	147	153	160

TABLE 4-4. Effect of growth curve (LOW, STANDARD, or HIGH) on carcass traits and ovarian morphology at time of photostimulation (A-Group birds)

Variable	Growth Curve			Pooled SEM
	LOW	STANDARD	HIGH	
Number of birds	24	24	24	
BW, g	1631[a]	1815[b]	1969[c]	23
Shank length, mm	103.1[a]	104.2[ab]	104.9[b]	0.6
Water content				
%BW	67.19[a]	66.70[a]	66.46[a]	0.33
g	1063[a]	1174[b]	1268[c]	14
Protein content				
%BW	20.22[a]	20.10[a]	20.31[a]	0.34
g	320.2[a]	354.8[b]	387.8[c]	6.7
Fat content				
%BW	6.01[a]	6.79[ab]	7.24[b]	0.35
g	96.2[a]	120.1[b]	138.3[b]	6.7
Ash content				
%BW	3.27[a]	3.25[a]	3.32[a]	0.09
g	51.6[a]	57.4[b]	63.2[c]	1.5
Liver lipid				
%Liver	3.92[a]	3.87[a]	3.70[a]	0.16
%BW	0.071[a]	0.074[a]	0.069[a]	0.003
g	1.15[a]	1.33[b]	1.35[b]	0.04
Liver				
%BW	1.84[a]	1.94[a]	1.89[a]	0.05
g	29.8[a]	35.0[b]	37.1[b]	0.9
Breast				
%BW	15.38[a]	15.56[a]	15.76[a]	0.18
g	251.5[a]	282.7[b]	310.2[c]	5.6
Abdominal fatpad				
%BW	0.29[a]	0.44[ab]	0.53[b]	0.06
g	4.9[a]	8.1[b]	10.5[b]	1.1
Oviduct				
%BW	0.025[a]	0.037[a]	0.028[a]	0.005
g	0.42[a]	0.69[a]	0.56[a]	0.10
Ovary				
%BW	0.036[a]	0.039[a]	0.037[a]	0.002
g	0.58[a]	0.71[b]	0.73[b]	0.03
Number of SYF[1]	0	0	0	
Number of LYF[2]	0	0	0	

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).

SYF[1] = small yellow follicles.

LYF[2] = large yellow follicles.

TABLE 4-5. Effect of photostimulation age (19WK or 21WK) on carcass traits and ovarian morphology at the time of photostimulation (A-Group birds)

Variable	Photostimulation Age 19WK	21WK	Pooled SEM
Number of birds	36	36	
Age, wk	19	21	
BW, g	1700[a]	1910[b]	19
Shank length, mm	103.7[a]	104.4[a]	0.5
Water content			
%BW	66.74[a]	66.82[a]	0.27
g	1097[a]	1240[b]	12
Protein content			
%BW	19.42[a]	21.00[b]	0.28
g	319.5[a]	389.0[b]	5.5
Fat content			
%BW	6.44[a]	6.92[a]	0.28
g	107.6[a]	128.8[b]	5.5
Ash content			
%BW	3.19[a]	3.37[a]	0.07
g	52.4[a]	62.3[b]	1.2
Liver lipid content			
%Liver	3.88[a]	3.78[a]	0.13
%BW	0.076[b]	0.066[a]	0.002
g	1.29[a]	1.26[a]	0.04
Liver			
%BW	1.99[b]	1.79[a]	0.04
g	33.8[a]	34.2[a]	0.8
Breast			
%BW	15.58[a]	15.56[a]	0.15
g	265.6[a]	297.4[b]	4.6
Abdominal fatpad			
%BW	0.41[a]	0.43[a]	0.05
g	7.2[a]	8.4[a]	0.9
Oviduct			
%BW	0.018[a]	0.042[b]	0.004
g	0.30[a]	0.82[b]	0.08
Ovary			
%BW	0.038[a]	0.037[a]	0.001
g	0.65[a]	0.70[a]	0.03
Number of SYF[1]	0	0	
Number of LYF[2]	0	0	

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).

SYF[1] = small yellow follicles.

LYF[2] = large yellow follicles.

TABLE 4-6. Effect of the growth curve x photostimulation age interaction (LOW19, STANDARD19, HIGH19, LOW21. STANDARD21 or HIGH21) on carcass traits and ovarian morphology at time of photostimulation (A-Group birds)

	Growth Curve x Photostimulation Age						Pooled SEM
Variable	LOW19	STAND19	HIGH19	LOW21	STAND21	HIGH21	
Number of birds	12	12	12	12	12	12	
Age, wk	19	19	19	21	21	21	
BW, g	1541^{a}	1714^{b}	1846^{c}	1722^{b}	1915^{c}	2093^{d}	32
Shank length, mm	103.8^{ab}	103.8^{ab}	103.5^{ab}	102.3^{a}	104.7^{bc}	106.3^{c}	0.8
Water content							
%BW	67.67^{a}	66.50^{a}	66.05^{a}	66.70^{a}	66.90^{a}	66.86^{a}	0.47
g	1011^{a}	1102^{b}	1176^{c}	1114^{b}	1246^{d}	1360^{e}	20
Protein content							
%BW	19.37^{a}	19.13^{a}	19.76^{ab}	21.08^{b}	21.06^{b}	20.87^{b}	0.49
g	288.9^{a}	317.5^{b}	352.1^{c}	351.4^{c}	392.1^{d}	423.4^{e}	9.5
Fat content							
%BW	5.35^{a}	6.39^{ab}	7.58^{b}	6.67^{ab}	7.20^{b}	6.90^{b}	0.49
g	80.3^{a}	106.6^{ab}	136.0^{cd}	112.1^{bc}	133.6^{cd}	140.7^{d}	9.5
Ash content							
%BW	3.19^{a}	3.08^{a}	3.30^{a}	3.36^{a}	3.42^{a}	3.34^{a}	0.12
g	47.6^{a}	51.1^{ab}	58.6^{cd}	55.7^{bc}	63.6^{de}	67.7^{e}	2.1
Liver lipid content							
%Liver	3.99^{a}	3.63^{a}	4.02^{a}	3.85^{a}	4.12^{a}	3.39^{a}	0.23
%BW	0.075^{b}	0.076^{b}	0.077^{b}	0.068^{ab}	0.071^{b}	0.060^{a}	0.004
g	1.15^{a}	1.30^{ab}	1.43^{b}	1.16^{a}	1.36^{b}	1.26^{ab}	0.06
Liver							
%BW	1.88^{a}	2.11^{b}	1.96^{ab}	1.79^{a}	1.77^{a}	1.82^{a}	0.07
g	28.9^{a}	36.2^{cd}	36.2^{cd}	30.7^{ab}	33.8^{bc}	38.0^{d}	1.3
Breast							
%BW	15.15^{a}	15.57^{a}	16.02^{a}	15.62^{a}	15.55^{a}	15.50^{a}	0.26
g	233.5^{a}	267.1^{b}	296.1^{c}	269.6^{b}	298.4^{c}	324.3^{d}	8.0
Abdomin fatpad							
%BW	0.20^{a}	0.43^{ab}	0.58^{b}	0.37^{ab}	0.45^{b}	0.47^{b}	0.08
g	3.1^{a}	7.6^{ab}	11.0^{b}	6.6^{ab}	8.6^{b}	10.0^{b}	1.6
Oviduct							
%BW	0.016^{a}	0.020^{ab}	0.016^{a}	0.034^{abc}	0.054^{c}	0.039^{bc}	0.007
g	0.25^{a}	0.35^{a}	0.30^{a}	0.60^{ab}	1.02^{c}	0.83^{bc}	0.14
Ovary							
%BW	0.037^{a}	0.039^{a}	0.038^{a}	0.034^{a}	0.040^{a}	0.036^{a}	0.002
g	0.57^{a}	0.67^{abc}	0.71^{bc}	0.59^{ab}	0.76^{c}	0.75^{c}	0.05
Number of SYF[1]	0	0	0	0	0	0	
Number of LYF[2]	0	0	0	0	0	0	

^{a,b,c} Means within a row with no common superscript differ significantly ($P < 0.05$).

SYF [1] = small yellow follicles. LYF [2] = large yellow follicles.

NB no significant interaction effect of growth curve x photostimulation age for any variable.

TABLE 4-7. Effect of growth curve (LOW, STAND, or HIGH) on carcass traits and ovarian morphology at sexual maturity (B-Group birds)

Variable	Growth Curve LOW	STANDARD	HIGH	Pooled SEM
Number of birds	20	20	20	
Age at first egg, d	183.5[b]	178.0[a]	173.3[a]	1.8
BW, g	2585[a]	2648[ab]	2720[b]	44
Shank length, mm	107.3[a]	107.2[a]	107.1[a]	0.8
Water content				
%BW	64.04[b]	63.42[b]	62.49[a]	0.32
g	1594[a]	1624[a]	1627[a]	27
Protein content				
%BW	20.43[a]	20.36[a]	20.62[a]	0.29
g	508.0[a]	521.5[a]	536.9[a]	10.8
Fat content				
%BW	10.18[a]	10.36[a]	11.22[a]	0.46
g	254.2[a]	266.7[ab]	292.0[b]	13.0
Ash content				
%BW	3.48[a]	3.39[a]	3.40[a]	0.07
g	86.4[a]	86.7[a]	88.3[a]	2.1
Liver lipid content				
%Liver	11.56[a]	10.46[a]	10.99[a]	1.21
%BW	0.210[a]	0.186[a]	0.203[a]	0.030
g	5.46[a]	5.08[a]	5.52[a]	0.73
Liver				
%BW	1.82[a]	1.73[a]	1.83[a]	0.05
g	47.2[a]	46.0[a]	49.6[a]	1.7
Breast				
%BW	16.49[ab]	17.06[b]	16.29[a]	0.20
g	426.3[a]	451.4[a]	443.4[a]	10.0
Abd. fatpad				
%BW	1.45[a]	1.54[a]	1.68[a]	0.12
g	37.9[a]	41.3[a]	45.5[a]	3.4
Oviduct				
%BW	2.56[a]	2.46[a]	2.44[a]	0.07
g	66.3[a]	65.3[a]	66.1[a]	2.0
Ovary				
%BW	2.11[a]	2.07[a]	1.98[a]	0.07
g	43.2[a]	43.2[a]	45.4[a]	1.9
Stroma				
%BW	0.267[a]	0.263[a]	0.297[a]	0.031
g	6.9[a]	7.0[a]	8.0[a]	0.8
Number of SYF[1]	10.2[a]	11.0[a]	13.5[a]	1.1
Number of LYF[2]	6.8[a]	7.0[a]	7.8[a]	0.3
Percent of LYF within 1 g	22.80[a]	29.46[a]	48.17[b]	5.71

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).
SYF [1] = small yellow follicles.
LYF [2] = large yellow follicles.

TABLE 4-8. Effect of photostimulation age (19WK or 21WK) on carcass traits and ovarian morphology at time of sexual maturation (B-Group birds)

Variable	Photostimulation Age 19WK	21WK	Pooled Sem
Number of birds	30	30	
Age at first egg, d	174.3[a]	182.1[b]	1.5
BW, g	2584[a]	2718[b]	36
Shank length, mm	106.3[a]	108.1[a]	0.7
Water content			
%BW	63.56[a]	63.07[a]	0.26
g	1583[a]	1647[b]	22
Protein content			
%BW	20.45[a]	20.49[a]	0.24
g	509.5[a]	534.8[b]	8.8
Fat content			
%BW	10.52[a]	10.65[a]	0.37
g	262.5[a]	279.5[a]	10.6
Ash content			
%BW	3.47[a]	3.37[a]	0.06
g	86.4[a]	88.0[a]	1.7
Liver lipid content			
%Liver	12.32[a]	9.69[a]	0.99
%BW	0.218[a]	0.181[a]	0.020
g	5.74[a]	4.96[a]	0.59
Liver			
%BW	1.73[a]	1.86[b]	0.042
g	44.8[a]	50.4[b]	1.4
Breast			
%BW	16.86[a]	16.35[b]	0.17
g	436.1[a]	444.6[a]	8.2
Abdominal fatpad			
%BW	1.57[a]	1.54[a]	0.10
g	40.9[a]	42.4[a]	2.7
Oviduct			
%BW	2.42[a]	2.56[a]	0.06
g	62.4[a]	69.4[b]	1.7
Ovary			
%BW	2.08[a]	2.04[a]	0.06
g	43.1[a]	44.7[a]	1.6
Stroma			
%BW	0.277[a]	0.274[a]	0.025
g	7.1[a]	7.5[a]	0.6
Number of SYF[1]	10.8[a]	12.3[a]	0.9
Number of LYF[2]	7.2[a]	7.2[a]	0.3
Percent of LYF within 1 g (%)	33.4[a]	33.5[a]	4.7

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).
SYF [1] = small yellow follicles. LYF [2] = large yellow follicles.

TABLE 4-9. Effect of the growth curve x photostimulation age interaction (LOW19, STANDARD19, HIGH19, LOW21, STANDARD21, or HIGH21) on carcass traits and ovarian morphology at sexual maturity (B-Group birds)

	Growth Curve x Photostimulation Age						Pooled SEM
Variable	LOW19	STAND19	HIGH19	LOW21	STAND21	HIGH21	
Number of birds	10	10	10	10	10	10	
Age at first egg, d	179.3^{bc}	174.1^{ab}	169.6^{a}	187.6^{c}	181.8^{bc}	176.9^{b}	2.6
BW, g	2536^{a}	2592^{a}	2624^{a}	2635^{a}	2704^{ab}	2816^{b}	63
Shank length, mm	106.4^{a}	106.6^{a}	105.9^{a}	108.2^{a}	107.7^{a}	108.3^{a}	1.2
Water content							
%BW	64.05^{b}	64.25^{b}	62.37^{a}	64.02^{b}	62.59^{a}	62.61^{a}	0.46
g	1566^{a}	1611^{ab}	1570^{a}	1621^{ab}	1637^{ab}	1684^{b}	39
Protein content							
%BW	20.67^{a}	19.99^{a}	20.70^{a}	20.19^{a}	20.73^{a}	20.55^{a}	0.41
g	505.8^{a}	501.3^{a}	521.5^{ab}	510.3^{ab}	541.7^{ab}	552.3^{b}	15.3
Fat content							
%BW	10.36^{a}	9.73^{a}	11.47^{a}	9.99^{a}	11.00^{a}	10.97^{a}	0.64
g	253.4^{a}	245.0^{a}	289.1^{a}	255.0^{a}	288.5^{a}	294.9^{a}	18.4
Ash content							
%BW	3.54^{a}	3.43^{a}	3.42^{a}	3.41^{a}	3.34^{a}	3.37^{a}	0.10
g	86.7^{a}	86.1^{a}	86.4^{a}	86.2^{a}	87.4^{a}	90.3^{a}	3.0
Liver lipid content							
%Liver	13.13^{a}	9.80^{a}	14.02^{a}	9.99^{a}	11.11^{a}	7.96^{a}	1.71
%BW	0.224^{ab}	0.171^{ab}	0.260^{b}	0.195^{ab}	0.202^{ab}	0.146^{a}	0.035
g	5.71^{a}	4.61^{a}	6.92^{a}	5.21^{a}	5.55^{a}	4.11^{a}	1.03
Liver							
%BW	1.70^{a}	1.66^{a}	1.82^{ab}	1.94^{b}	1.79^{ab}	1.84^{ab}	0.07
g	43.1^{a}	43.4^{a}	47.9^{ab}	51.3^{b}	48.5^{ab}	51.3^{b}	2.4
Breast							
%BW	16.47^{a}	17.52^{b}	16.60^{a}	16.50^{a}	16.60^{a}	15.97^{a}	0.29
g	417.9^{a}	453.9^{a}	436.5^{a}	434.7^{a}	448.8^{a}	450.3^{a}	14.1
Abdominal fatpad							
%BW	1.50^{a}	1.51^{a}	1.71^{a}	1.39^{a}	1.58^{a}	1.65^{a}	0.17
g	38.2^{a}	39.7^{a}	44.6^{a}	37.7^{a}	43.0^{a}	46.4^{a}	4.7
Oviduct							
%BW	2.52^{ab}	2.32^{a}	2.42^{ab}	2.61^{b}	2.61^{b}	2.46^{ab}	0.10
g	63.7^{ab}	60.1^{a}	63.4^{ab}	68.8^{b}	70.5^{b}	68.8^{b}	2.9
Ovary							
%BW	2.24^{b}	1.94^{ab}	2.05^{ab}	1.99^{ab}	2.21^{ab}	1.92^{a}	0.13
g	44.2^{a}	41.2^{a}	43.9^{a}	42.1^{a}	45.2^{a}	47.0^{a}	2.7
Stroma							
%BW	0.265^{a}	0.243^{a}	0.322^{a}	0.269^{a}	0.283^{a}	0.272^{a}	0.044
g	6.7^{a}	6.4^{a}	8.3^{a}	7.1^{a}	7.7^{a}	7.6^{a}	1.1
Number of LYF[1]	6.9^{a}	7.0^{a}	7.6^{a}	6.7^{a}	6.9^{a}	7.9^{a}	0.5
Number of SYF[2]	10.2^{a}	10.1^{a}	12.2^{a}	10.1^{a}	11.9^{a}	14.8^{a}	1.5
Percent of LYF within 1 g (%)	26.07^{a}	32.02^{ab}	42.13^{ab}	19.52^{a}	26.9^{a}	54.19^{b}	0.08

^{a,b,c} Means within a row with no common superscript differ significantly ($P < 0.05$).

SYF [1] = small yellow follicles. LYF [2] = large yellow follicles.

NB no significant interaction effect of growth curve x photostimulation age for any variable.

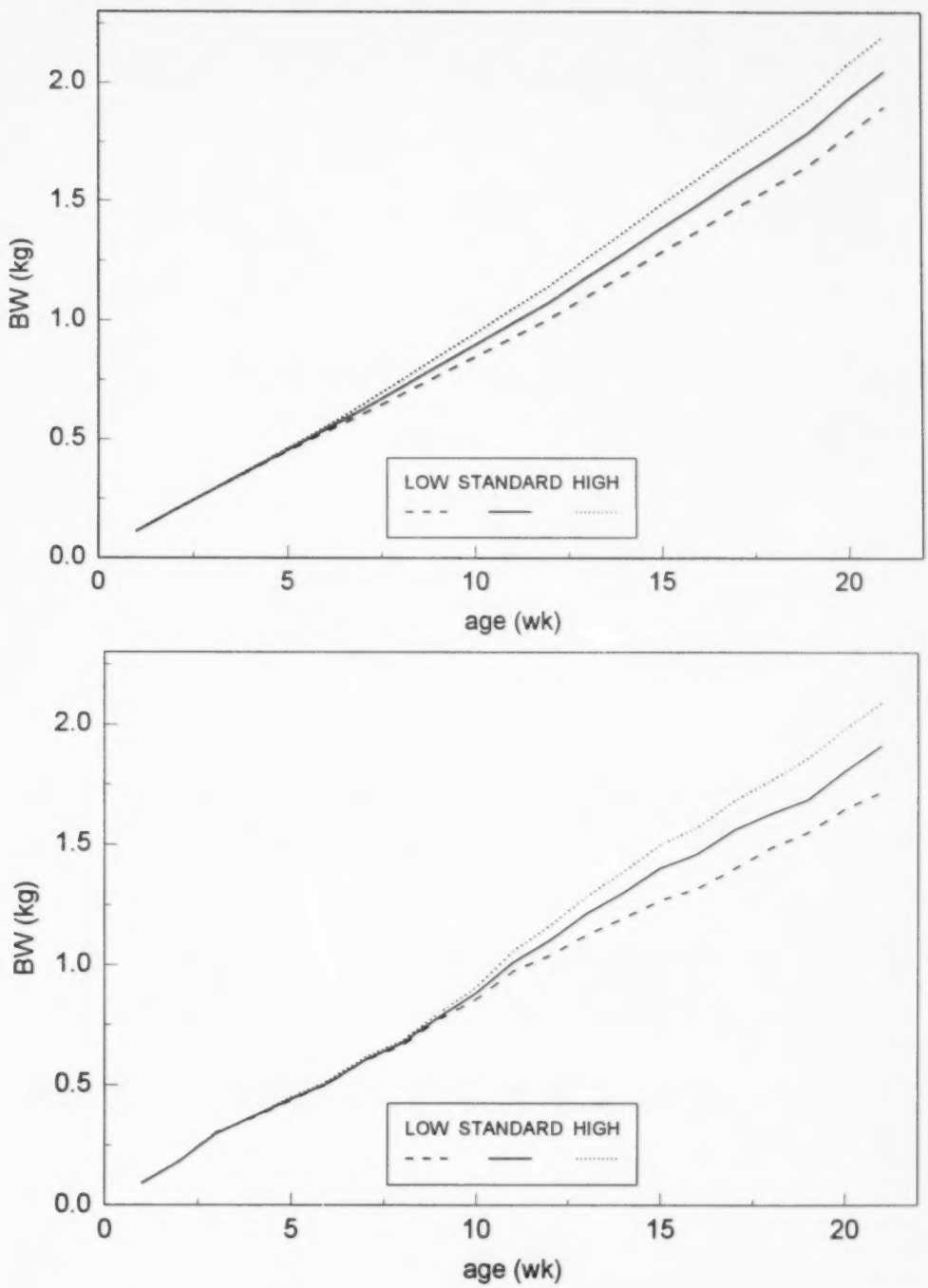

FIGURE 4-1. Upper panel: Body weight targets for the main effect of growth curve (LOW, STANDARD or HIGH) from wk 1 through to processing. Lower panel: Actual weekly BW of all birds up to 17 wk of age and only A-Group birds from 18 wk of age to processing (day of photostimulation).

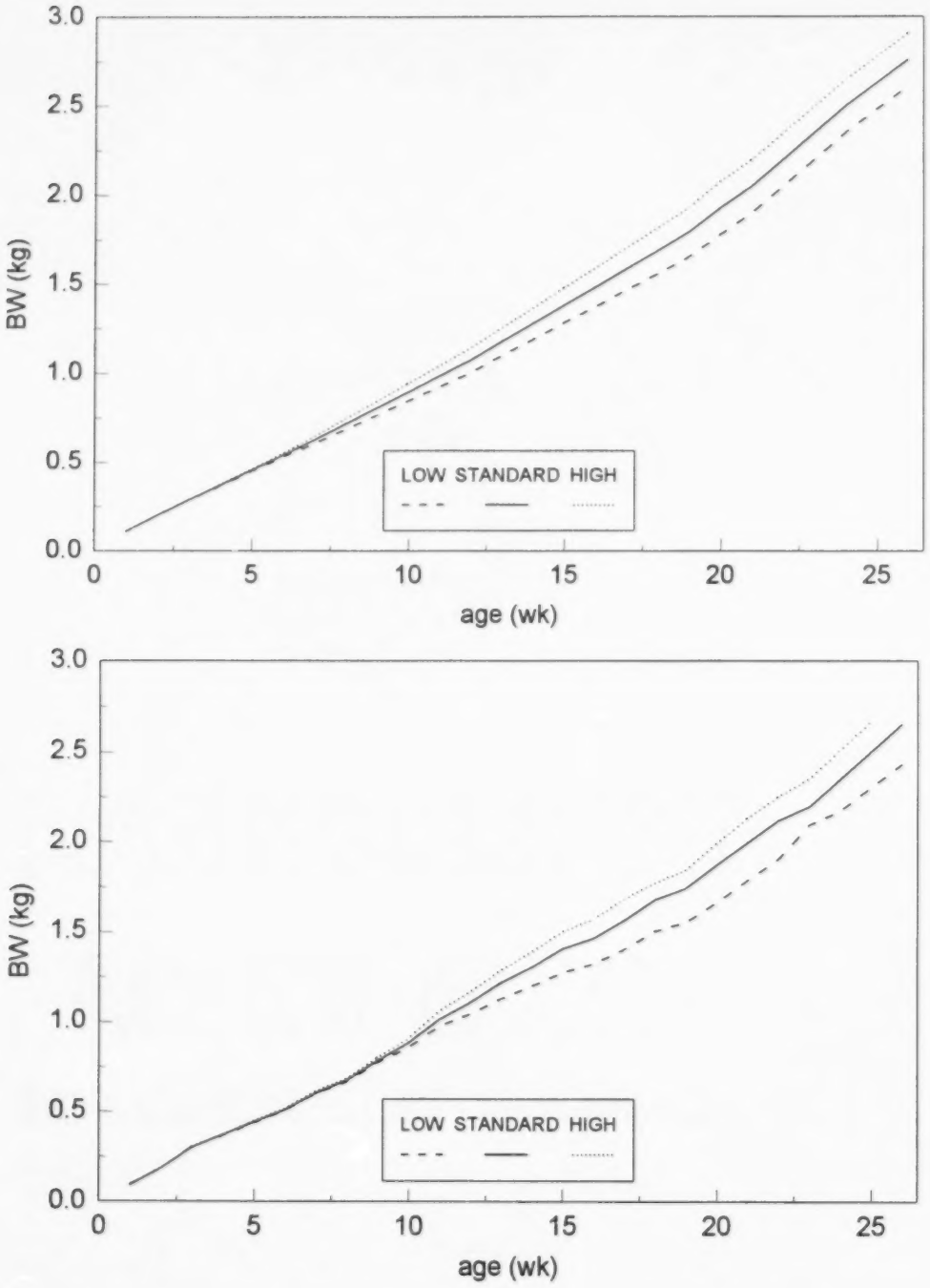

FIGURE 4-2. Upper panel: Body weight targets for the main effect of growth curve (LOW, STANDARD or HIGH) from wk 1 through to processing. Lower panel: Actual weekly BW of all birds up to 17 wk of age and only the B-Group birds from 18 wk of age to processing (sexual maturity). Weekly BW means are not presented when there were fewer than 6 birds per treatment.

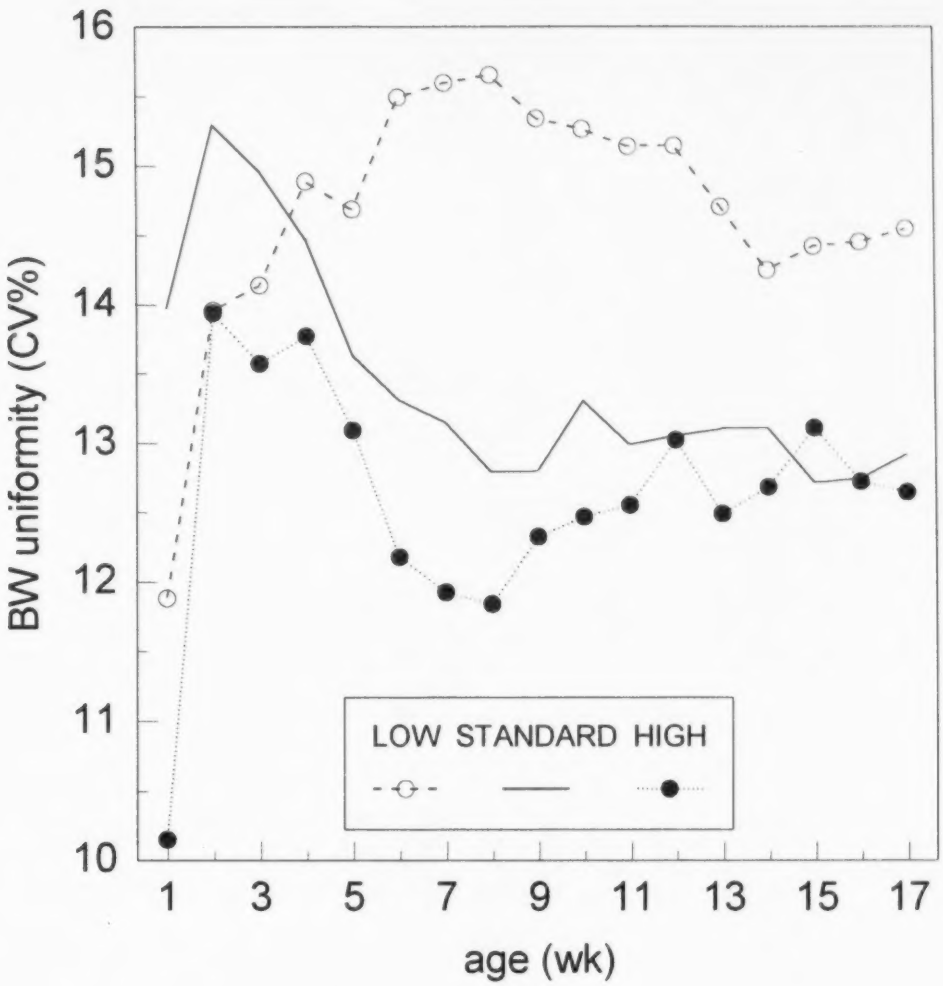

FIGURE 4-3. Body weight uniformity estimates of all birds during the rearing phase (0 to 17 wk) for the main effect of growth curve (LOW, STANDARD or HIGH). Uniformity is expressed as the coefficient of variation of BW.

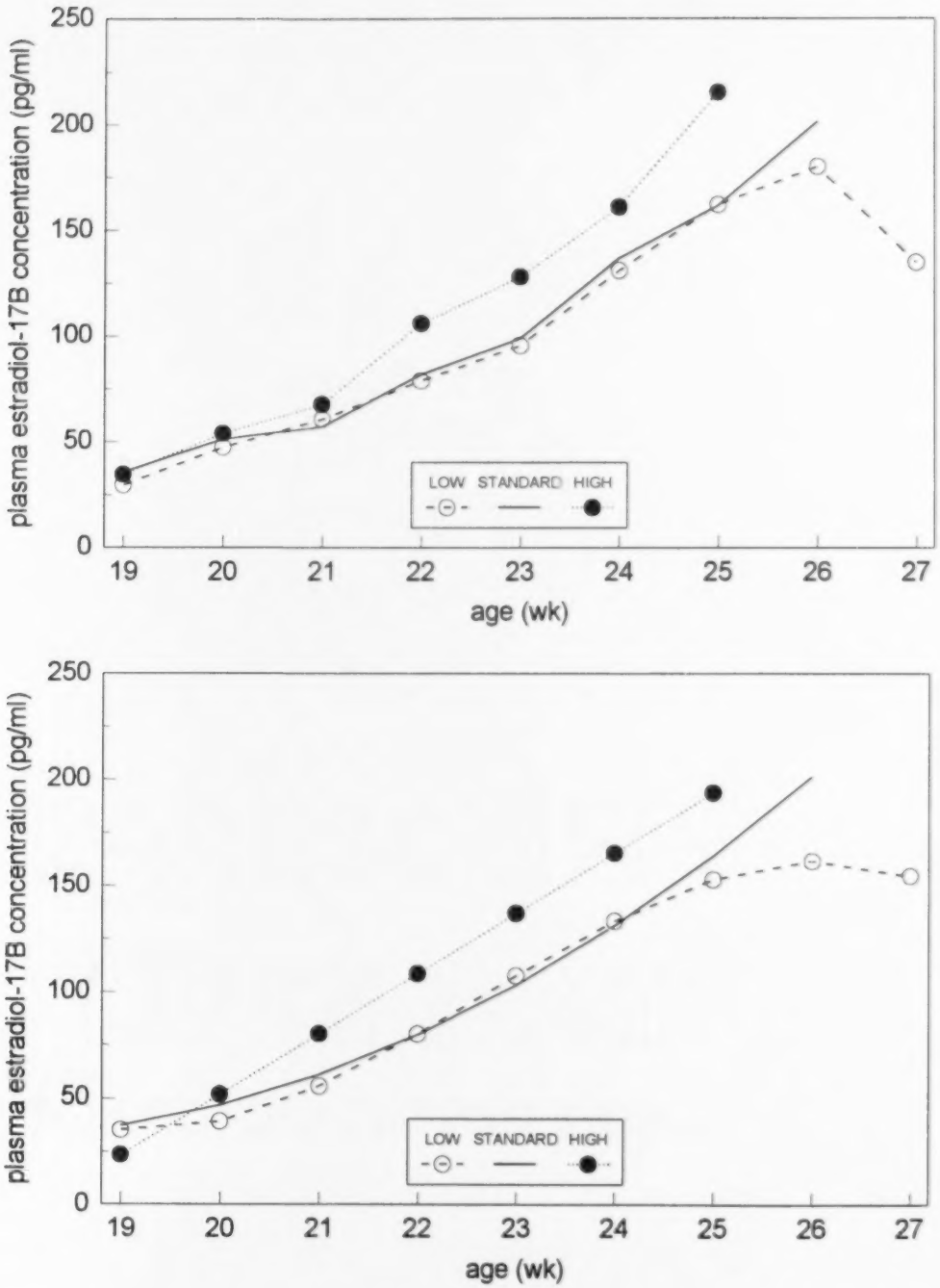

FIGURE 4-4. Upper panel: Actual estradiol-17β profiles of the B-Group birds for the main effect of growth curve (LOW, STANDARD or HIGH). Lower panel: Predictive estradiol-17β profiles for the B-Group birds of the main effect of growth curve for the LOW (R^2=0.475), STANDARD (R^2=0.596) or HIGH (R^2=0.464) treatments. Weekly estradiol-17β means are not presented when there were less than 6 birds per treatment.

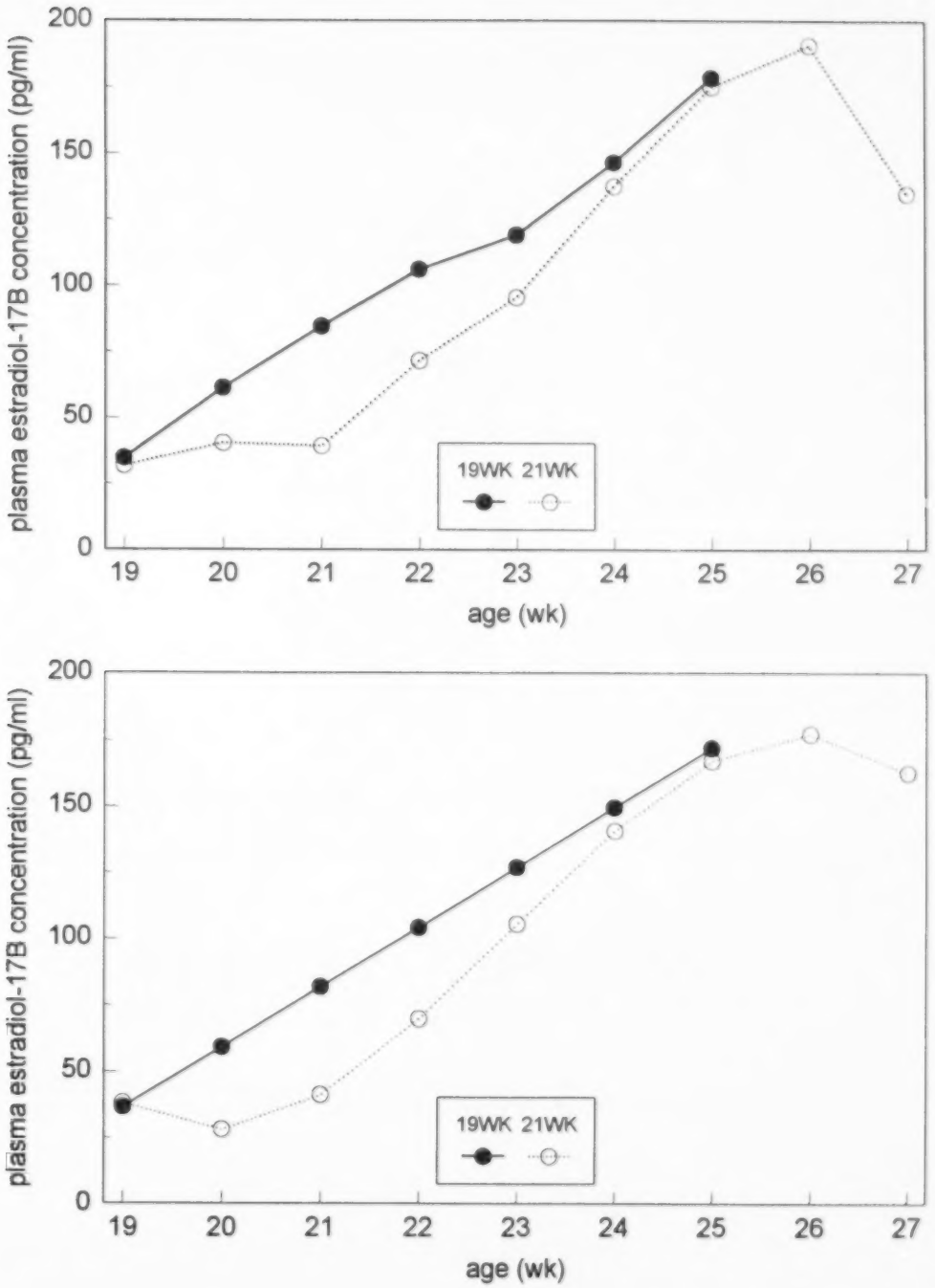

FIGURE 4-5. Upper panel: Actual estradiol-17β profiles of the B-Group birds for the main effect of photostimulation age (19WK or 21WK). Lower panel: Predictive estradiol-17β profiles for the B-Group birds for the main effect of growth curve for the 19WK (R^2=0.456) and the 21WK (R^2=0.557) treatments. Weekly estradiol-17β means are not presented when there were less than 6 birds per treatment.

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5. THE EFFECT OF SMALL DIFFERENCES IN GROWTH CURVE AND AGE AT PHOTOSTIMULATION IN FEMALE BROILER BREEDERS. 2. REPRODUCTIVE PERFORMANCE, AND CARCASS TRAITS AND OVARIAN MORPHOLOGY AT 61 WK OF AGE

5.1 INTRODUCTION

Recent studies have shown that *ad-libitum* feeding of broiler breeder hens is detrimental to hen livability, total egg production, fertility and hatchability (Hocking, 1993; Katanbaf *et al.*, 1989; Robinson *et al*, 1991b; and Yu *et al.*, 1992a, 1992b). Work by Hocking *et al.* (1987, 1989), Hocking (1993), Robinson *et al.* (1991a, 1991b), and Yu *et al.*(1992a, 1992b, 1992c) makes clear that feed restriction during the rearing and breeding periods improves reproductive performance by limiting the development of the follicular hierarchy. A reduction in the number of LFY at sexual maturity through feed restriction is associated with a subsequent increased rate of lay (Hocking *et al.*, 1987; Yu *et al.*, 1992b).

In recent years, primary breeder target BW for broiler breeder females have been lowered and the recommended age at photostimulation has been postponed until later in order to improve reproductive performance. The effect of these trends are not well documented in the literature. Yuan *et al.* (1994) found that when broiler breeder pullets were allowed to attain greater than recommended BW targets, accompanied by early photostimulation, total egg production was not improved. Wautier (1994) compared different photostimulatory ages from 120 to 160 d of age and demonstrated a negative effect of earlier age at lighting on chick production. In spite of inducing longer time in lay, earlier photostimulation has not been associated with improved rates of egg production (Wautier, 1994; Yuan *et al.*, 1994). Fattori *et al.* (1991a) grew broiler breeders on BW targets above and below standard recommended BW targets. They found that birds grown on higher BW targets produced more double-yolked eggs. Birds grown on BW targets lower than the recommended BW target entered lay later and were considered to have acceptable rates of lay to an older age than birds grow on heavier BW targets. All levels of feed restriction used by Fattori *et al.* (1991a) ensured equivalent intake of all required nutrients except energy. Yu *et al.* (1992c)

have shown that among full fed hens, the F2 follicle can produce high levels of progesterone and low levels of androstenedione and thus may be as capable of ovulating in response to a LH surge as the F1 follicle. Hocking (1993) has shown that the number of LYF at sexual maturity was directly proportional to BW in broiler breeders. Robinson *et al.* (1995) examined the effect of fast feeding (rapid increases in feed allocation) versus slow feeding (gradual increases in feed allocation) in the period of 20 to 25 wk of age as well as the effect of slow photostimulation (step up increases in daylength) with fast photostimulation (on step increase in daylength) on reproductive performance. They found that the effect of slow photoperiod and fast feeding increased ovary weight at sexual maturity. Fast feeding increased the numbers of LYF at sexual maturity from 7.9 to 8.9. There was a 10.9 egg reduction in the fast feeding program that was associated with the reduced control of the follicular recruitment process prior to sexual maturity. Wilson *et al.* (1995) reported that broiler breeders reared on an early slow growth curve laid fewer eggs through to 62 wk of age than birds reared on a linear or on a early fast growth curve. Broiler breeder females are very sensitive to small differences in feeding program.

The modern broiler breeder female is continually changing in response to selection pressure for desirable reproductive and growth traits. The female line is partially selected for growth characteristics. Genetic gains in broiler growth are realized by the female parent. Research with modern broiler breeder females is needed in order for management programs to keep pace with the changing parent female. Examination of carcass traits and ovarian morphology at the end of lay can be a valuable procedure to characterize the effects of rearing and breeding treatments. It can also determine the relationship between reproductive performance, carcass traits and ovarian morphology for individual hens. Very little data of this sort exists. The following experiment was conducted in order to determine the effect of small differences in growth curve and age at photostimulation on reproductive performance. In addition, the relationship between reproductive performance with carcass traits and ovarian morphology at the end of lay was investigated.

5.2 *MATERIALS AND METHODS*

5.2.1 Stocks and Management

Detailed descriptions of the experimental design, stocks, rearing feeding regimens, rations, housing facilities, and photostimulatory programs were described in Chapter 4. Briefly, 450 broiler breeder pullets were grown on three different growth curves: as recommended by the breeder (STANDARD), lower BW target (LOW) and higher BW target (HIGH). The LOW and HIGH treatments were 150 g below and above the STANDARD treatment at 20 wk of age, respectively, as shown in Figure 5-1. Feed allocations for the breeding period are shown in Table 5-1. All birds were individually weighed weekly in the morning prior to being fed. At 18 wk of age the 116 birds within each growth curve that were closest to their respective targets were individually caged and assigned a photostimulation age of 19 wk of age (19WK) or 21 wk of age (21WK). There were 58 birds in each of the six treatment combinations (LOW19, STANDARD19, HIGH19, LOW21, STANDARD21 and HIGH21). All individually caged birds were assigned to a group. Twelve birds for each treatment combination were assigned to the A-Group and were processed at photostimulation. Ten birds for each treatment combination were assigned to the B-Group and were blood sampled weekly and processed the morning after their first egg. Thirty-six birds for each treatment combination were assigned to the C-Group and were individually caged to 61 wk of age to assess individual egg production and were processed at 61 wk of age. Each interaction of 36 birds was divided into two lots of 18 birds each. All birds were individually weighed weekly and BW uniformity was determined weekly as the coefficient of variation of BW within a lot.

The C-Group birds are the focus of this chapter. A total of fourteen C-Group birds were not included in the egg production data set because they were either culled or they died. Birds were culled because of oviductal prolapse (n=2), broken femurs (n=3), failure to enter lay by 35 wk (n=2), and complete cessation of lay after less than 2 wk of production (n=2). Birds died of heart attacks (n=3), necrotic enteritis (n=1), and self inflicted injury (n=1). During the 60th wk, one LOW21 bird died of a heart attack. While this hen was included in the production data set, she was not included in the 61 wk

processing data set. There were 202 birds in the production data set and 201 birds in the 61 wk processing data set. The experimental protocol was approved by the Faculty of Agriculture, Forestry and Home Economics, of the University of Alberta's Faculty Animal Policy and Welfare Committee.

5.2.2 Laying Records

Sexual maturity was defined as the age at first oviposition. In order not to confound BW measurements with feed intake, all birds were weighed the morning of the laying of the first egg (morning egg) or the following day (afternoon egg), before being fed. Individual daily egg production records were maintained for each hen and all eggs were marked according to type (normal, soft shelled, shelless, double yolk, broken but not soft shelled, abnormal shell, pecked).

Sequence analysis was applied to the data. A sequence was defined as a period of consecutive ovipositions separated by a pause of one or more days. In the event that a hen laid two eggs on one day, one of the eggs could not fill a preceding or subsequent pause day. If a sequence occurred entirely within a 1 wk period (defined as whole integers of bird age in wk) it contributed to the average sequence length for that wk only. If a sequence was longer than one day and covered more than 1 calendar wk, then that sequence length was entered for each wk that it occurred within. Each day of the wk was assigned a sequence length number based on the sequence length that occurred on that day (0 and higher). The sequence length numbers for each of the 7 d of the week were averaged to arrive at the average sequence length for that wk. Pauses in egg production were averaged into the average weekly sequence length as 0. The prime sequence was defined as the longest egg sequence around the time of peak production. The sequence length and prime sequence length were determined for individual hens. Individual egg laying data were examined and any incidence of a temporary cessation in egg laying for greater than 21 d was noted. This phenomenon was designated as a long-pause.

All eggs from a hen were weighed at oviposition until two consecutive eggs of 52 g or more were laid. The hen age at the time of the second 52 g egg was recorded and designated as the settable egg age. Once a hen had reached the settable egg age, one normal shelled egg from each hen was weighed each wk. Egg weights were averaged on a monthly basis for each hen. Uniformity estimates of age at sexual

maturity, BW at sexual maturity, and settable egg age, were expressed as the coefficient of variation of the mean, as well as the percent of birds within ± 5, 10 and 15% of the mean. All uniformity estimates were calculated within a lot.

5.2.3 Fertility, Hatchability, and Embryo Viability

Sixty individually caged Shaver Starbro males were housed in the same room as the females and were managed following the primary breeder recommendations. Hens were artificially inseminated with 0.05 ml pooled undiluted semen on the day they laid their first egg. Subsequently, hens were artificially inseminated weekly. Eggs were collected daily and sorted by lot. Starting at 27 wk of age all eggs were shipped to a commercial hatchery[1] on a weekly basis. On the day of the hatch, all non-hatched eggs were broken open and scored macroscopically as: infertile, embryonic death occurring during stage 1 (0-7 d incubation), stage 2 (8-14 d incubation), or stage 3 (later than 14 d incubation) of development, dead in shell (pipped but dead), or cull chick. Percent fertility and hatchability were determined on an individual hen basis. Hatchability was defined as the number of viable chicks, excluding cull chicks, obtained from the total number of eggs set (hatchability of eggs set). Hatchability of fertile eggs set was defined as the number of viable chicks, excluding cull chicks, hatched divided by the number of fertile eggs set. The number of chicks was defined as the potential number of viable chicks produced per hen (average hatchability of set for each hen multiplied by number of settable eggs laid for that hen).

5.2.4 Bird Processing at 61 wk of Age

At 61 wk of age all of the 201 C-Group birds were processed in the same manner to that used for the B-Group birds as described in Chapter 4. Birds were randomly selected and killed by cervical dislocation at 0600 h to 1200 h without being fed. All birds were processed on the same day within a 6 h period. Chemical analysis was not conducted on the C-Group birds. All carcass traits and ovarian morphology characteristics were calculated in the same manner to that used for the B-Group birds as

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[1]Lilydale Co-operative Ltd., Edmonton, AB, Canada T5C 1R9

described in Chapter 4.

5.2.5 Statistical Analysis

Data were subject to a two-way analysis of variance with the sources of variation, growth curve, photostimulation age, and the interaction of growth curve x photostimulation age. When significant differences were determined for growth curve the comparisons were made among the growth curve least squares-means using Fisher's protected least significant difference procedure. If either or both of the main effects of growth curve or photostimulation age were significant, comparisons were made among the six growth curve x photostimulation age least-squares means using the least significant difference procedure. For consistency of presentation the six growth curve x photostimulation age least-squares means are presented for all variables. For all variables except uniformity estimates, the error variation consisted of the variation between birds within growth curve x photostimulation age. The error variation for all uniformity estimates consisted of the variation between lots within growth curve x photostimulation age.

Pearson correlation coefficients of the interrelationships among individual traits were computed across birds within the C-Group. Correlations between prime sequence length and wk 40, wk 44, wk 48, wk 52, wk 56 and wk 60 average sequence lengths were computed across all C-Group birds in order to determine if peak production negatively affected persistency of lay. Correlations between average sequence lengths from wk 28 to wk 60 were computed across all C-group birds and across the STANDARD birds. The number of eggs produced in the last 8 d of the laying cycle were correlated to carcass traits and ovarian morphology at 61 wk of age. Stepwise regression analysis were used on the C-Group bird data set to evaluate the influence of carcass and ovarian traits at 61 wk of age on production parameters.

The 61 wk processing data were combined with the reproductive performance data and the birds were ranked into the upper and lower 50% and the upper and lower 25% for total numbers of eggs produced and prime sequence length. Body weight and ovarian morphology characteristics at 61 wk of age for the upper 50% of the birds for total eggs produced or prime sequence length were compared to the lower 50% of the birds for the respective ranking parameter. The same was done with the upper and lower

25% rankings. Means were subject to an one way Analysis of Variance using SAS (SAS Institute, 1994). This was done in order to determine the BW and ovarian morphology characteristics at 61 wk of birds who had performed either well or poorly. All calculations were carried out using SAS (SAS Institute, 1994). All significance was assessed at the $P < 0.05$ level.

5.3 RESULTS AND DISCUSSION

5.3.1 Growth, Uniformity and Sexual Maturity

Details of BW and uniformity during the rearing period are given in Chapter 4. Target and actual BW growth curves are shown in Figure 5-1. At 22, 26, 27 and 28 wk of age the 19WK birds were significantly lower in BW than the 21WK birds. This was most likely because the feed allocation of the 19WK birds was not sufficient to maintain BW gains during the onset of rapid ovarian development and egg production. The 21WK birds would not have had these requirements at this time due to later photostimulation cue. The BW growth curves of the interaction groups are shown in Figure 5-2. Weekly BW of the LOW19 and HIGH19 birds were not different from the LOW21 and HIGH21 birds, respectively. The STANDARD19 birds had a significantly lower BW at 27, 28, and 29 wk of age compared to the STANDARD21 birds.

The only significant uniformity difference between the three growth curves (Table 5-2) or the two photostimulation ages (Table 5-3) was on the uniformity of BW at sexual maturity (percentage of birds within $\pm$ 15% of the mean). The LOW birds were more uniform in BW at sexual maturity at the $\pm$ 15% level than the STANDARD birds and not different from the HIGH birds. Error variation was high due to the small number of observations (six for photostimulation age, four for growth curve and two for the interaction) and the relatively small number of birds within a uniformity estimate (14 to 18 birds). Uniformity of weekly BW was not different between growth curves or photostimulation ages (Figure 5-3). As birds approached sexual maturity, BW uniformity estimates were improved in all treatments and they slowly worsened through to the end of lay. From 18 wk of age to sexual maturity, BW uniformity estimates improved because all birds were being fed individually. Larger birds no longer received a larger

proportion of the allocated feed, as was likely the case in the floor pens. After sexual maturity, birds had different rates of egg production and thus had different levels of energy available for BW gain. A flock with high BW uniformity is easier to manage since a large percentage of the birds will have similar nutritional requirements throughout the rearing and breeding periods (Anonymous, 1994d). For this reason it was of interest to calculate uniformity estimates for age at sexual maturity, BW at sexual maturity and settable egg age. Birds entering lay in a highly non-uniform manner (BW or age) would result in feed allocation being either too generous or not sufficient for a large proportion of the birds. While some hens would become increasingly overweight, others would not be able to maintain high rates of lay and achieve the growth required in the period from photostimulation to peak egg production. Uniformity in age at the onset of production of settable eggs was also of interest. A highly uniform settable egg age would make it easier to determine when to start shipping eggs to the hatchery.

The main effect of growth curve (Table 5-5) had a significant effect on the BW at sexual maturity. Body weight at sexual maturity of the HIGH (2747 g), and the STANDARD (2652 g) birds were heavier than the BW of the LOW birds (2444 g). Age at sexual maturity was positively correlated to BW at sexual maturity (r=0.677). Fattori *et al.* (1991a) also found a delay in sexual maturity proportional to the level of feed restriction. As indicated by the age at sexual maturity, the days from photostimulation to sexual maturity, and the settable egg age, the HIGH birds were able to respond to the photostimulatory cue faster and lay a settable egg sooner than the LOW or STANDARD birds (Table 5-5). Previous studies have shown that increasing BW during rearing advances age at sexual maturity in broiler breeder hens (Robbins *et al.*, 1986, Yu *et al.*, 1992b, Yuan *et al.*, 1994). However, the differences in BW used in this study are smaller than those used in previous studies. Neither the weight of the first egg (overall mean $\pm$ SEM = 45.0 $\pm$ 0.6 g) or the days from sexual maturity to a settable egg (overall mean $\pm$ SEM = 12.6 $\pm$ 1.2 d) were different between the three growth curves. Rates of increase in egg weight did not differ between the three growth curves. Fattori *et al.* (1993) found that while small differences in feed allocation before sexual maturity delay the onset of sexual maturity and the development of carcass and reproductive traits, after sexual maturity carcass and reproductive traits were all similar. The B-Group bird data (processed at sexual maturity) in Chapter 4 support these conclusions. Thresholds for carcass traits and ovarian

morphology characteristics were shown to exist independent of the treatment effect.

The main effect of photostimulation age had a significant effect on several production parameters associated with sexual maturity (Table 5-6). The 19WK birds laid their first egg at a lower BW (19WK = 2547 g, 21WK = 2681 g) and at a earlier age (19WK = 174.5 d, 21WK = 179.4 d) than the 21WK birds. Age at sexual maturity was advanced and BW at sexual maturity was decreased by earlier photostimulation, as has been shown previously (Yuan *et al.*, 1994). The 19WK birds were delayed in responding to photostimulation as indicated by the days from photostimulation to sexual maturity (19WK = 41.7 d, 21WK = 32.2 d) and at sexual maturity the 19WK birds laid a smaller first egg (19WK = 43.9 g, 21WK = 46.0 g). This is in contrast to Wautier (1994) who reported no difference in the weight of the first egg between a wide range in photostimulation ages. While it took longer for the 19WK birds to achieve a settable egg after sexual maturity (19WK = 14.7 d, 21WK = 10.6 d) the settable egg age was not different. Wautier (1994) also showed that days from photostimulation to sexual maturity decreased with delayed photostimulation. There was no interaction effect of growth curve x photostimulation age (Table 5-7). These results are supported by the correlation analysis. Age at sexual maturity was correlated with settable egg age (r=0.440), days from photostimulation to sexual maturity (r=0.731) and days from sexual maturity to settable egg age (r=-0.550). Individual birds that laid their first egg at a later age tended to lay a settable egg at a later age, take longer to respond to the photostimulatory cue and once in lay require a shorter period of time to lay a settable egg.

There was no significant effect of either growth curve or photostimulation age on estimates of flock uniformity, with the one noted exception. Uniformity estimates for all variables were very good compared to what would be expected in a commercial operation. This was a consequence of excluding excessively heavy or light weight birds from the experiment at the time of individual caging. Growth curve did not have an effect on the weight of the first egg or on the days from sexual maturity to a settable egg. While the HIGH birds entered lay sooner, growth curve did not appear to advance sexual maturity beyond an age at which the birds could be termed premature for initiation for egg production. Earlier photostimulation age not only advanced age at sexual maturity but also reduced the weight of the first egg and delayed the attainment of a settable egg after sexual maturity. Photostimulation at 19 wk of age

advanced age at sexual maturity to a point where birds may not have been fully mature, as indicated by the weight of thier first egg and their imparied ability to increase egg size after sexual maturity.

5.3.2 Egg Production

Of the 202 birds that were included in the egg production data set, 23 birds exhibited one or more long-pauses. Three birds had two such long-pauses and the other 20 hens had one. Three of the birds were within a long-pause at the time of processing, all other birds had reinitiated egg production by this time. Six of the long-pauses occurred between 43 and 47 wk of age and the other 20 long-pauses occurred between 50 and 61 wk of age. The incidence of long-pauses by treatment were as follows; LOW19 = 1, STANDARD19 = 10, HIGH19 = 6, LOW21 = 1, STANDARD21 = 3, and HIGH21 = 5. It was not clear if these incidents of long-pauses were molts due to stress, either induced by disease or environment, or were caused by a reduction in the rate of follicular maturation (Williams and Sharp, 1978). A reduction in the rate of follicular maturation may have been induced by an increase rate of follicular atresia (Palmer and Bahr, 1992), reduced follicular sensitivity to LH (Johnson *et al.*, 1986) or the onset of photorefractoriness (Sharp *et al.*, 1992). The occurrence of these long pauses are one of the greatest sources of reproductive inefficiency in broiler breeder hens.

There was no effect of the different growth curves on the number of sequences observed (overall mean $\pm$ SEM = 61.4 $\pm$ 1.4), the average sequence length (overall mean $\pm$ SEM = 3.0 $\pm$ 01 d) or the prime sequence length (overall mean $\pm$ SEM = 16.0 $\pm$ 1.3 d) (Table 5-8). The STANDARD birds laid fewer total eggs (171.4) than either the LOW (180.4) or the HIGH (182.3) birds. However, the numbers of normal eggs produced as well as the numbers of settable eggs produced were not different between the growth curves because the STANDARD birds laid fewer soft shelled eggs than the LOW birds. There was a higher incidence of long-pauses within the STANDARD birds possibly resulting in the lower numbers of total eggs produced.

The STANDARD birds also had numerically (non-significant) longer prime sequence lengths than the LOW or the HIGH birds. There is some concern within the meat-type chicken breeder industry that birds that have long prime sequence lengths may be prone to having reduced persistency of lay (Robinson,

AFNS, University of Alberta, Edmonton, Alberta, T6G 2P5, personal communication). However, correlations between prime sequence length and wk 40, wk 44, wk 48, wk 52, wk 56 and wk 60 average sequence lengths were significant and positive (Table 5-9). In addition, the mean prime sequence length of the birds exhibiting a long-pause was not different from the flock average. There was an increase in the average sequence length of the STANDARD birds around the time of peak production (Figure 5-4). However, average sequence length around the time of peak production (wk 28 and wk 32) and average sequence length later in lay (wk 34 to wk 60) were positively correlated when computed across all birds and across only the STANDARD birds. Thus, the reduced levels of total egg production in the STANDARD birds appeared to be partially a function of their increased incidence of long-pauses late in lay, the cause of which was unclear.

As BW target increased, the percentage of double yolked eggs laid and the total number of double yolked eggs laid increased. The HIGH birds laid both a higher proportion and a higher number of total double yolked eggs to 61 wk of age (0.25%, 0.5) than the LOW birds (0.05%, 0.1) (Table 5-8). Fattori *et al.* (1991a) found that broiler breeder hens grown on lower BW targets laid a lower proportion of double yolked eggs (8% below standard BW = 1.23%) than birds grown on higher BW targets (8% above standard BW = 0.7%). The HIGH birds also laid both a higher proportion and a higher number of double yolked eggs to 33 wk of age (0.77%, 0.4) than the STANDARD birds (0.36%, 0.2), and the LOW birds (0.17%, 0.1). The levels double-yolked egg production reported here are very small compared to those expected under commercial conditions.

The majority of the double yolked eggs laid were laid in the interval of time from sexual maturity through peak egg production. Feed restricted broiler breeder hens have fewer LYF late in lay than they do early in lay (Lupiki, 1994). Thus, there would be less likelihood of two LYF being sufficiently mature to ovulate at the same time. The higher percent of LYF within 1 g observed in the B-Group HIGH birds at sexual maturity (Chapter 4) is associated with higher numbers of double-yolked eggs laid in the C-Group HIGH birds. However, it did not appear to result in a difference of total eggs laid in the C-Group HIGH birds (Table 5-8). The higher percent of LYF within 1 g in the HIGH birds may result in F2 follicles possessing functional similarities (high progesterone production with low androstenedione production) to

F1 follicles as has been shown with full fed broiler breeder hens (Yu *et al.*, 1992c). This may result in multiple ovulations within one open period for luteinizing hormone release leading to the production of double yolked eggs and defective eggs (Robinson *et al.*, 1993). The condition know as erratic ovulation defective egg syndrome (EODES), described by Jaap and Muir (1968) and van Middelkoop (1971, 1972), involves laying throughout the photoperiod and scotoperiod, laying more than one egg per day, and laying a higher proportion of multiple yolk eggs. While the condition has been well characterized in the *ad-libitum* fed broiler breeder (Yu *et al.*, 1992b), these results suggest that small differences in BW target and feed allocation can also induce EODES. While some incidence of double yolk egg production is expected, any incidence of it can be termed unacceptable from a reproductive efficiency or chick production point of view.

The 19WK birds had more egg laying sequences than the 21WK birds whereas the number of total and settable eggs were the same (Table 5-10). The sequence length was not different (P=0.054) between the 19WK birds (2.85 d) and the 21WK birds (3.09 d). The sequence length profiles and hen day egg production growth curves are shown in Figures 5-5 for the main effects of photostimulation age. Yuan *et al.* (1994) also found that in spite of a longer time in lay, total eggs produced to 64 wk were the same between early (14 and 17 wk of age) and later (20 wk of age) photostimulatory programs. Wautier (1994) concluded that delayed photostimulation results in faster response to photostimulation, longer prime sequence length, fewer sequences of larger duration leading to the production of similar numbers of eggs. Among the differences in BW used here, the data do not support advancing age at photostimulation for above target weight flocks.

The prime sequence length was correlated to total eggs (r=0.485) and to settable eggs (r=0.478). Robinson *et al.* (1990) reported a significant positive correlation of r=0.399 between prime sequence length and total egg production. The relationship between prime sequence length and egg production may be of use to primary breeders in determining selection criteria for their pedigree stocks, especially considering the evidence presented here refuting the possible negative correlation between prime sequence length and sequence lengths later in lay.

The increased incidence of long-pauses may have been the cause of the reduced egg production in

the STANDARD birds, as opposed to an overall reduction in individual bird performance. The HIGH birds also laid more double yolked eggs suggesting the incidence of F2 follicles showing functional similarities as F1 follicles. A mild condition of EODES was evident in the HIGH birds. There was no difference in reproductive performance between the photostimulation ages. Although the 21WK birds entered lay 5 d later than the 19WK birds, they laid the same number of eggs in fewer a number of sequences. Based on these results, later photostimulation is favored over earlier photostimulation.

5.3.3 Egg Weight

The weight of the first egg was the same between all three growth curves. However, subsequently, monthly average egg weights for normal shelled eggs were consistently heavier in the HIGH birds compared to the LOW birds (Table 5-12). Fattori *et al.* (1991a) found no significant difference in weekly egg weight measurement between BW targets of 8% below standard BW target, standard BW target, and 8% above standard BW target. While numerical differences between Fattori *et al's* (1991a) three BW treatments were similar to those presented here, the SEMs were much smaller in the present trial. Larger eggs, shown in the present trial to be positively affected by hen BW, also tend to be of lower specific gravity (Harms *et al.*, 1990). However, it is unknown if eggs classified in the present trial as normal or settable have a reduced shell quality or embryo viability affected by BW. The birds photostimulated at 19 wk of age laid a smaller first egg than the birds photostimulated at 21 wk of age. Yet, there was no effect of photostimulation age on monthly averages of egg weights (Table 5-13). Wautier (1994) and Yuan *et al.* (1994) also found no effect of photostimulation age on mean egg weight.

5.3.4 Chick Production

Weekly incubation traits were summarized for the entire study (Tables 5-15 to 5-17). Fertility and hatchability was summarized monthly for each main effect and is presented in Figures 5-6 and 5-7. The STANDARD birds had higher hatchability of settable eggs (82.67%) and hatchability of fertile eggs set (90.45%) than the LOW birds (79.11%, 86.96%) and the HIGH birds (80.22%, 88.31%), respectively. Overall fertility was not different between the growth curves (overall mean $\pm$ SEM = 90.62 $\pm$ 0.37%) and

there was no apparent reduction in fertility over time (Figure 5-6 and 5-7). O'Sullivan *et al.* (1991) have shown reduced fertility with older hens to be an effect of male libido. In artificially inseminated flocks fertility does not decrease with time. The STANDARD birds had a lower proportion of stage 1, stage 2 and stage 3 embryonic losses than the LOW birds and a lower proportion of stage 1 and stage 3 embryonic losses than the HIGH birds. It is unclear why the STANDARD birds had a lower proportion of embryonic loss.

There was no effect of photostimulation age on the incubation traits (Table 5-16), supporting work by Wautier (1994). There were a number of significant interaction effects on incubation traits as shown in Table 5-17. The STANDARD21 birds (91.66%) had higher fertility than the LOW21 (89.84%) and the HIGH21 (89.84%) birds. The STANDARD21 birds (83.90%) also had higher hatchability of settable eggs than the STANDARD19 birds (81.45%). There was no difference in the numbers of chicks produced between the three growth curves (Table 5-18) and two photostimulation ages (Table 5-19). Hatchability of settable eggs was correlated to average sequence length (r=0.201), settable eggs (r=0.329) and normal eggs (r=0.338). Defective eggs were negatively correlated to chick numbers (r=-0.560), hatchability of settable eggs (r=-0.615) and hatchability of fertile eggs set (r=-0.727). No defective eggs were shipped to the hatchery, yet production of defective eggs was strongly negatively correlated to incubation traits. Based on this, the author would suggest a strong maternal effect on hatchability of settable eggs and hatchability of fertile eggs set related to defective egg production. It is unclear if the negative relationship between defective egg production and hatchability of settable eggs and hatchability of fertile eggs set was a function of embryo viability, shell quality or some combination of both.

First of sequence eggs tend to have a higher incidence of embryonic death (Robinson *et al.*, 1991a; Fasenko *et al.*, 1992). In addition, there is a strong positive relationship between long average sequence length and high egg production levels, as shown here, and as described by Robinson *et al.* (1993). The negative correlation between embryo viability and defective egg production may be due in part to the erratic laying of some hens. Erratic laying would result in a reduction in the average sequence length. There was a positive correlation between hatchability of settable eggs and average sequence length. A weak expression of erratic ovulation defective egg syndrome may be responsible for the negative

correlation between defective egg production and hatchability of settable eggs.

The amount of starter feed, grower feed, breeder feed and total feed allocated per chick produced was calculated on an individual hen basis (Table 5-18 to 5-20). There was no effect of any treatment on feed allocation per chick produced. Prior to individual caging at 18 wk of age, feed was allocated on a pen basis and after 18 wk feed was allocated on an individual bird basis. Consumption levels prior to individual caging assume that all birds within a pen consumed equal amount of feed. Higher feed restriction did not have an adverse effect on numbers of hatching eggs produced or on chick production capacity. In a commercial operation the difference in feed allocation between the LOW and the HIGH birds would represent a substantial quantity of feed. Fattori *et al.* (1991b) concluded that BW restriction below recommended levels was more economical than standard feeding practices. The present experiment supports this statement. Increased restriction of all required nutrients, not just energy, may be economically beneficial.

5.3.5 61 wk Carcass Traits and Ovarian Morphology - Relative to Reproductive Function

The shank length of the LOW birds (104.9 mm) was shorter than that of the STANDARD birds (106.9 mm) and the HIGH birds (107.9 mm) (Table 5-21). As previously shown (Fattori *et al.*, 1993), the higher degree of feed restriction appeared to have stunted the skeletal growth of the LOW birds. Liver weight, breast muscle weight and abdominal fatpad weight all increased in a dose response manner between the three BW growth curves. On an absolute basis the HIGH birds had a larger liver weight (55.7 g), breast muscle weight (599.6 g) and abdominal fatpad weight (226.2 g) than the STANDARD birds (49.7, 571.1 g, 190.8 g) and the LOW birds (48.7 g, 523.2 g, 154.6 g) respectively. Percent abdominal fatpad weight and absolute abdominal fatpad weight increased with increasing BW target (Table 5-21). This supports the conclusions for the A-Group birds (processed at photostimulation) and B-Group birds (processed at sexual maturity) that heavier birds within the range of BW used here not only had more carcass fat but had a higher proportion of carcass fat.

Absolute oviduct weight was not different between the growth curves. The percent oviduct weight was larger in the LOW birds (2.01%) compared to the STANDARD birds (1.80%) and the HIGH

birds (1.75%) by nature of the BW differences. Although it appeared that the oviduct reached a functional size regardless of BW, BW was negatively correlated (r=-0.302) to oviduct weight. Oviduct weight was positively correlated to ovary weight (r=0.536), number of LYF (r=0.429), total eggs (r=0.312), average sequence length (r=0.177), and chicks (r=0.286). Oviduct weight was negatively correlated to percent of LYF within 1 g (r=-0.268). These correlations were likely the result of the negative correlation between oviduct weight and 61 wk BW. Total eggs (r=-0.370), defective eggs (r=-0.115), prime sequence length (r=-0.156), average sequence length (r=-0.268) and chicks (r=-0.237) were all negatively correlated with BW at 61 wk of age. These results indicate an impaired egg and chick production capacity with larger BW birds. The percent of LYF within 1 g was positively correlated with BW (r=0.220) and defect eggs (r=0.265) and negatively correlated with total eggs (r=-0.151) and chicks (r=-0.269). While some of these correlations are weak, in all they suggest that the larger BW birds tended to have a higher percent of LYF within 1 g at 61 wk of age which may have resulted in laying more defective eggs and fewer total eggs, and producing fewer chicks.

The numbers of eggs produced in the last 8 d before processing was positively correlated with ovary weight (r=0.256) and percent ovary weight (r=0.372). Numbers of eggs produced in the last 8 d was negatively correlated with percent of LYF within 1 g (r=-0.299), 61 wk BW (r=-0.456), abdominal fatpad weight (r=-0.283) and percent abdominal fatpad weight (r=-0.182). Numbers of LYF at 61 wk were positively correlated to total eggs (r=0.193), prime sequence length (r=0.146) and average sequence length (r=0.243). The HIGH birds also had a larger ovary weight (44.7 g) than the LOW birds (39.2 g) and the STANDARD birds (37.7 g). However, like at photostimulation (A-Group birds) and at sexual maturity (B-Group birds), the percent ovary weight in the C-Group birds at 61 wk of age was not different between the three growth curves.

There was no effect of growth curve or photostimulation age on the incidence of atresia, internal ovulation or internal laying. There was no difference (P=0.085) in the incidence of follicular atresia between the HIGH (10.8%), STANDARD (7.4%) or LOW (1.4%) birds. There was also no difference (P=0.065) in the rate of internal laying between the HIGH (6.1%), STANDARD (1.5%) or the LOW (0.0%) birds. However, atresia was positively correlated with BW at 61 wk (r=0.247) and BW at sexual

maturity (r=0.162). Hocking (1993) concluded that the proportion of atresia among yellow follicles and the incidence of internal ovulation increases with BW at sexual maturity. These results suggest that the proportion of atresia among yellow follicles increases with BW at the end of lay.

The incidence of atresia was negatively correlated with the production parameters total eggs (r=-0.246), normal eggs (r=-0.261), settable eggs (r=-0.272), average sequence length (r=-0.213) and chicks (r=-0.186). However, while the incidence of atresia was not correlated to ovary weight, LYF, SYF, or the percent of LYF within 1 g, it was negatively correlated to absolute oviduct weight (r=-0.215) and percent oviduct weight (r=-0.259). Ovulation rate is the product of follicular recruitment and growth, and the incidence of follicular atresia (Gilbert *et al.*, 1983). Atresia is common among the SYF as an alternative to growth, yet among the LYF (> 8 mm) atresia is rare (Gilbert *et al.*, 1983). Unfortunately, in the present study, follicular atresia was not distinguished between the SYF or the LYF, but rather was identified among SYF and LYF together. It is unclear whether the rate of atresia among yellow follicles itself was responsible for the reduced egg production or if atresia was a factor of BW.

Where significant differences existed between growth curves, variables for the most part responded in a dose response manner as would be expected. However, over the production cycle the STANDARD birds laid fewer total eggs than the LOW birds and HIGH birds, fewer soft shelled eggs than the LOW birds, and had higher hatchability of settable eggs and hatchability of fertile eggs set than the LOW and the HIGH birds. At 61 wk of age the STANDARD birds also had smaller percent liver weights than the LOW birds and two fewer SYF than the HIGH birds. It is unclear why the STANDARD birds responded in this way or if the lower percent liver weight or fewer SYF had an effect on egg production. In this trial, percent liver weight and SYF numbers at the end of lay were not correlated to any measure of reproductive function.

The only effect of photostimulation age at 61 wk of age was on the liver weight (Table 5-22). The 19WK birds had larger liver weights (52.6 g) than the 21WK birds (50.0 g). Yu *et al.* (1992a) and Robinson *et al.* (1995) have shown a significant effect of an early lay treatment on liver weight. Generally, carcass traits and reproductive morphology at the end of lay are not affected by early lay period treatment but rather depend on feed allocation and egg production levels during the later breeding period

(Robinson *et al.*, 1995).

Stepwise regression was computed with all carcass traits and ovarian morphology traits recorded at 61 wk of age against the dependent variables normal eggs (R^2=0.283), settable eggs (R^2=0.115) and defective eggs (R^2=0.263). Coefficients in front of the significant variable in the regression model indicate the change in the dependent variable associated with the change of one unit of the independent variable holding all other independent variables in the model constant;

normal eggs = 134.50 - 0.48(abdominal fatpad weight)
+ 20.05(percent abdominal fatpad weight) + 10.99(percent ovary weight)
- 17.45 (percent of LYF within 1 g) + 2.82 (no. LYF),

settable eggs = 423.02 - 0.08(BW) - 11.03(percent liver weight) + 3.29(ovary weight)
- 111.08 (percent oviduct weight) + 14.01 (percent ovary weight),

defective eggs = 27.76 -0.01(BW) + 17.93 (percent of LYF within 1 g).

Size of the ovary had a positive effect on the number of normal and settable eggs laid. Percent of LYF within 1 g had a negative influence on normal egg production and a positive effect on defective eggs production.

Yu *et al.* (1992b) demonstrated that feed restriction can reduce the incidence of erratic laying, which was shown to be positively correlated with defective egg production and negatively correlated with settable egg production. In the present trial, there was a negative correlation between 61 wk BW and total egg production, prime sequence length, average sequence length, and chick numbers. There was also a positive correlation between 61 wk BW and the percent of LYF within 1 g, and defective egg numbers. The heavier birds at the end of lay may have been laying erratically. The negative influence of the percent of LYF within 1 g on normal egg numbers and the positive influence of the percent of LYF within 1 g on defective egg numbers support these conclusions.

The BW and ovarian morphology characteristics at 61 wk of age of hens differing in numbers of total eggs produced and prime sequence length was determined (Table 5-24). Hens producing high numbers of total eggs (upper 50% and upper 25% of the flock) had longer prime sequence lengths, lower BW, heavier ovary weights, more LYF, and a fewer percent of LYF within 1 g at 61 wk of age than hens

producing at lower numbers of total eggs (lower 50% and lower 25% of the flock). The prime sequence lengths of those birds within the top 25% of the flock for total egg production (25.8 d) were over two and a half times longer than the prime sequence length of those birds within the bottom 25% of the flock for total egg production (10.1 d). Similarly, hens having longer prime sequences (upper 50% and upper 25% of the flock) laid more total eggs, were lighter in BW (upper 50% of the flock only) had larger ovary weights, and had more LYF at 61 wk of age than hens having shorter prime sequence lengths (lower 50% and lower 25% of the flock). It has been suggested that reduced rates of lay may be due in part to reduced follicular recruitment into the large yolky follicle pool, and a shortage of LYF necessary for high rates of egg production exists late in lay (Williams and Sharp, 1978; Palmer and Bahr, 1992). The reduction of the numbers of LYF from peak production to end of lay may be due to the gradual onset of photorefractoriness (Sharp *et al.*, 1992). Those birds no longer sensitive to long day lengths would be expected to have reduced rates of follicular recruitment thus reducing egg production rates. These results support this hypothesis in that birds with more LYF at the end of lay laid more total eggs, and had a longer prime sequence and average sequence length. While excess LYF early in lay have been shown to inhibit reproductive function and encourage the production of double yolked, soft shelled, shelless and abnormal eggs (Robinson *et al.*, 1993), a shortage of LYF later in lay appears to limit egg production levels at that time.

TABLE 5-1. Feed allowances of the six different growth curve x photostimulation age interactions (LOW19, STANDARD19, HIGH19, LOW21, STANDARD21 or HIGH21) from 18 to 61 wk of age, all birds were individually caged and fed individually on a daily basis

	Growth Curve x Photostimulation Age					
Age	LOW19	STAND19	HIGH19	LOW21	STAND21	HIGH21
(wk)	(g per bird per d)					
18 to 19	67	76	85	67	76	85
19 to 20	70	79	88	70	79	88
20 to 21	73	82	91	73	82	91
21 to 22	78	85	94	78	85	94
22 to 23	87	93	102	87	93	100
23 to 24	96	102	111	96	102	109
24 to 25	105	111	120	105	111	118
25 to 26	114	120	129	114	120	127
26 to 27	126	132	141	123	129	136
27 to 28	132	138	147	129	135	142
28 to 29	138	144	153	135	141	148
29 to 30	147	153	162	147	153	160
30 to 31	154	158	167	154	158	167
31 to 32	154	158	167	154	158	167
32 to 33	152	156	165	152	156	165
33 to 34	152	154	165	152	154	165
34 to 35	150	152	163	152	152	163
35 to 36	148	150	161	148	150	161
36 to 37	146	148	159	146	148	159
37 to 38	144	146	157	144	146	157
38 to 39	143	145	156	143	145	156
39 to 40	141	143	154	141	143	154
40 to 41	139	141	152	139	141	152
41 to 42	137	139	150	137	139	150
42 to 43	136	138	149	136	138	149
43 to 44	136	138	149	136	138	149
44 to 45	134	136	147	134	136	147
45 to 46	132	134	145	132	134	145
46 to 47	131	133	142	131	133	142
47 to 48	131	133	142	131	133	142
48 to 49	131	133	142	131	133	142
49 to 50	133	135	144	133	135	144
50 to 51	133	135	144	133	135	144
51 to 52	133	135	144	133	135	144
52 to 53	132	134	143	132	134	143
53 to 54	132	134	143	132	134	143
54 to 55	133	135	144	133	135	144
55 to 56	133	135	144	133	135	144
56 to 57	131	133	142	131	133	142
57 to 58	130	132	141	130	132	141
58 to 59	128	130	139	128	130	139
59 to 60	127	129	138	127	129	138
60 to 61	127	129	138	127	129	138

TABLE 5-2. The effect of growth curve (LOW, STANDARD or HIGH) on estimates of uniformity of body weight at sexual maturity (SM), age at SM, and settable egg age

Variable and Uniformity Estimate	Growth Curve LOW	STANDARD	HIGH	Pooled SEM
BW at SM				
% within ± 5% of the mean	51.15[a]	44.45[a]	49.63[a]	9.50
%within ± 10% of the mean	82.33[a]	82.48[a]	76.85[a]	5.84
% within ± 15% of the mean	95.65[b]	88.20[a]	91.10[ab]	1.40
Coefficient of Variation, %	7.87[a]	8.93[a]	8.10[a]	1.27
Age at SM				
% within ± 5% of the mean	79.00[a]	81.10[a]	76.18[a]	6.42
%within ± 10% of the mean	95.65[a]	95.50[a]	96.83[a]	1.82
% within ± 15% of the mean	98.53[a]	95.50[a]	98.60[a]	1.48
Coefficient of Variation, %	4.19[a]	4.76[a]	4.62[a]	0.59
Settable egg age[1]				
% within ± 5% of the mean	72.43[a]	77.95[a]	73.10[a]	5.91
%within ± 10% of the mean	95.75[a]	95.65[a]	95.83[a]	2.14
% within ± 15% of the mean	98.60[a]	100.00[a]	100.00[a]	0.81
Coefficient of Variation, %	4.24[a]	4.20[a]	4.56[a]	0.44

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).
Settable egg age[1] = hen age at second consecutive egg weighing over 52 g.

TABLE 5-3. The effect of photostimulation age (19WK or 21WK) on estimates of uniformity of body weight at sexual maturity (SM), age at SM, and settable egg age

Variable and Uniformity Estimate	Photostimulation Age 19WK	21WK	Pooled SEM
BW at SM			
% within ± 5% of the mean	41.47[a]	55.35[a]	7.75
%within ± 10% of the mean	77.43[a]	83.67[a]	4.77
% within ± 15% of the mean	90.02[a]	93.28[a]	1.15
Coefficient of Variation, %	9.58[a]	7.02[a]	1.04
Age at SM			
% within ± 5% of the mean	79.87[a]	77.65[a]	5.24
%within ± 10% of the mean	93.95[a]	98.03[a]	1.49
% within ± 15% of the mean	97.05[a]	98.03[a]	1.21
Coefficient of Variation, %	5.02[a]	4.02[a]	0.48
Settable egg age[1]			
% within ± 5% of the mean	73.05[a]	75.93[a]	4.82
%within ± 10% of the mean	96.18[a]	95.30[a]	1.75
% within ± 15% of the mean	99.07[a]	100.0[a]	0.66
Coefficient of Variation, %	4.49[a]	4.18[a]	0.36

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).
Settable egg age[1] = hen age at second consecutive egg weighing over 52 g.

TABLE 5-4. The effect of growth curve x photostimulation age (LOW19, STANDARD19, HIGH19, LOW21, STANDARD21, or HIGH21) on estimates of uniformity of body weight at sexual maturity (SM), age at SM, and settable egg age

	Growth Curve x Photostimulation Age						
Variable and Uniformity Estimate	LOW-19	STAND-19	HIGH-19	LOW-21	STAND-21	HIGH-21	Pooled SEM
BW at SM							
% within ± 5% of the mean	42.50[a]	38.20[a]	43.70[a]	59.80[a]	50.70[a]	55.55[a]	13.43
%within ± 10% of the mean	76.80[a]	85.10[a]	70.40[a]	87.85[a]	79.85[a]	83.30[a]	8.26
% within ± 15% of the mean	91.30[a]	88.20[a]	90.55[a]	100.0[b]	88.20[a]	91.65[a]	1.99
Coefficient of Variation, %	9.44[a]	10.14[a]	9.16[a]	6.30[a]	7.73[a]	7.04[a]	1.80
Age at SM							
% within ± 5% of the mean	76.80[a]	88.20[a]	74.60[a]	81.20[a]	74.00[a]	77.75[a]	9.08
%within ± 10% of the mean	91.30[a]	94.10[a]	96.45[a]	100.0[a]	96.90[a]	97.20[a]	2.57
% within ± 15% of the mean	97.05[a]	94.10[a]	100.0[a]	100.0[a]	96.90[a]	97.20[a]	2.09
Coefficient of Variation, %	5.24[a]	5.29[a]	4.70[a]	3.14[a]	4.23[a]	4.70[a]	0.83
Settable egg age[1]							
% within ± 5% of the mean	62.90[a]	82.30[a]	73.95[a]	81.95[a]	73.60[a]	72.25[a]	8.35
%within ± 10% of the mean	94.45[a]	94.10[a]	100.0[a]	97.05[a]	97.20[a]	91.65[a]	3.03
% within ± 15% of the mean	97.20[a]	100.0[a]	100.0[a]	100.0[a]	100.0[a]	100.0[a]	1.14
Coefficient of Variation, %	4.88[a]	4.37[a]	4.22[a]	3.60[a]	4.03[a]	4.91[a]	0.62

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).
Settable egg age[1] = hen age at second consecutive egg weighing over 52 g.

TABLE 5-5. Effect of growth curve (LOW, STANDARD or HIGH) on production parameters associated with sexual maturity (SM) (C-Group birds) (mean ± SEM)

	Growth Curve		
Variable	LOW	STANDARD	HIGH
Number of birds	68	68	66
BW at SM ,g	2444 ± 41[a]	2652 ± 41[b]	2747 ± 41[b]
Age at SM ,d	179.0 ± 1.1[b]	178.5 ± 1.1[b]	173.4 ± 1.1[a]
Days from photostimulation to SM	39.0 ± 1.1[b]	38.5 ± 1.1[b]	33.4 ± 1.1[a]
Weight of first egg ,g	45.0 ± 0.6[a]	45.6 ± 0.6[a]	44.3 ± 0.6[a]
Settable egg age[1] ,d	191.6 ± 1.1[b]	190.2 ± 1.1[b]	187.2 ± 1.1[a]
Days from SM to settable egg	12.6 ± 1.2[a]	11.5 ± 1.2[a]	13.8 ± 1.2[a]

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).
Settable egg age[1] = hen age at second consecutive egg weighing over 52 g.

TABLE 5-6. Effect of photostimulation age (19WK or 21WK) on production parameters associated with sexual maturity (SM) (C-Group birds) (mean ± SEM)

	Photostimulation Age	
Variable	19WK	21WK
Number of birds	99	103
BW at SM ,g	2547 ± 33[a]	2681 ± 34[b]
Age at SM ,d	174.5 ± 0.9[a]	179.4 ± 0.9[b]
Days from photostimulation to SM, d	41.7 ± 0.9	32.2 ± 0.8[a]
Weight of first egg, g	43.9 ± 0.49[a]	46.0 ± 0.48[b]
Settable egg age[1], d	189.2 ± 0.9[a]	190.0 ± 0.9[a]
Days from SM to settable egg, d	14.7 ± 1.0[b]	10.6 ± 1.0[a]

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).
Settable egg age[1] = hen age at second consecutive egg weighing over 52 g.

TABLE 5-7. Effect of the growth curve x photostimulation age interaction (LOW19, STANDARD19, HIGH19, LOW21, STANDARD21, or HIGH21) on production parameters associated with sexual maturity (SM) (C-Group birds) (mean ± SEM)

	Growth Curve x Photostimulation Age					
Variable	LOW19	STAND19	HIGH19	LOW21	STAND21	HIGH21
Number of birds	35	34	30	33	34	36
BW at SM,g	2388 ± 56^{a}	2560 ± 57^{bc}	2694 ± 60^{cd}	2500 ± 60^{ab}	2744 ± 59^{d}	2799 ± 56^{d}
Age at SM, d	177.6 ± 1.4^{bc}	175.4 ± 1.5^{b}	170.6 ± 1.5^{a}	180.4 ± 1.5^{c}	181.6 ± 1.5^{c}	176.1 ± 1.4^{b}
Days from photostim. to SM	44.6 ± 1.4 ^{c}	42.4 ± 1.7 ^{c}	37.6 ± 1.5^{b}	33.4 ± 1.5^{b}	34.6 ± 1.5^{b}	29.1 ± 1.4 ^{a}
Weight of first egg ,g	43.7 ± 0.8^{a}	44.9 ± 0.8^{ab}	43.3 ± 0.9^{a}	46.3 ± 0.9^{b}	46.2 ± 0.8^{b}	45.3 ± 0.8 ^{ab}
Settable egg age[1] ,d	192.3 ± 1.5^{b}	188.4 ± 1.5^{ab}	186.9 ± 1.6^{a}	190.8 ± 1.6^{ab}	191.9 ± 1.5^{b}	187.4 ± 1.5^{a}
Days from SM to settable egg	14.7 ± 1.7^{ab}	12.9 ± 1.7^{ab}	16.3 ± 1.8^{b}	10.4 ± 1.8^{a}	10.0 ± 1.7^{a}	11.3 ± 1.6^{a}

^{a,b,c} Means within a row with no common superscript differ significantly ($P < 0.05$).

Settable egg age[1] = hen age at second consecutive egg weighing over 52 g.

NB no significant interaction effect of growth curve x photostimulation age for any variable.

TABLE 5-8. Effect of growth curve (LOW, STANDARD or HIGH) on production parameters associated with egg production to 61 wk of age (C-Group birds) (mean ± SEM)

	Growth Curve		
Variable	LOW	STANDARD	HIGH
Number of birds	68	68	66
Number of sequences	61.3 ± 1.4[a]	61.1 ± 1.4[a]	61.9 ± 1.4[a]
Average sequence length	3.1 ± 0.1[a]	2.9 ± 0.1[a]	3.0 ± 0.1[a]
Prime Sequence length	14.7 ± 1.3[a]	16.8 ± 1.3[a]	16.4 ± 1.4[a]
Number of Ovulations	180.5 ± 2.6[b]	171.7 ± 2.6[a]	182.7 ± 2.6[b]
Total eggs	180.4 ± 2.6[b]	171.4 ± 2.6[a]	182.3 ± 2.6[b]
Settable eggs[1]			
%settable eggs[2]	89.3 ± 0.8[a]	91.9 ± 0.8[a]	90.0 ± 0.8[a]
total	160.4 ± 2.7[a]	157.5 ± 2.6[a]	164.1 ± 2.7[a]
Normal eggs[3]			
%normal eggs[2]	94.9 ± 0.7[a]	97.0 ± 0.7[a]	95.9 ± 0.7[a]
total	171.0 ± 2.7[a]	166.3 ± 2.7[a]	174.9 ± 2.8[a]
Soft shell eggs			
%soft shell eggs[2]	3.58 ± 0.50[b]	1.85 ± 0.50[a]	2.22 ± 0.51[ab]
total	6.7 ± 0.9[b]	3.1 ± 0.9[a]	4.1 ± 0.10[ab]
Shell-less eggs			
%shelless eggs[2]	0.40 ± 0.10[a]	0.44 ± 0.10[a]	0.41 ± 0.10[a]
total	0.7 ± 0.2[a]	0.8 ± 0.2[a]	0.7 ± 0.2[a]
Double yolk eggs			
%double yolk eggs to 61 wk of age[2]	0.05 ± 0.04[a]	0.15 ± 0.04[b]	0.25 ± 0.04[b]
total to 61 wk of age	0.1 ± 0.1[a]	0.3 ± 0.1[ab]	0.5 ± 0.1[b]
%double yolk eggs to 33 wk of age[2]	0.17 ± 0.13[a]	0.36 ± 0.13[a]	0.77 ± 0.13[b]
total to 33 wk of age	0.1 ± 0.1[a]	0.2 ± 0.1[a]	0.4 ± 0.1[b]
Abnormal shell eggs			
%abnormal shell[2]	1.11 ± 0.21[a]	0.62 ± 0.21[a]	1.21 ± 0.22[a]
total	2.0 ±0.4[a]	1.0 ± 0.38[a]	2.2 ± 0.41[a]

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).

[1]Normal eggs weighing over 52 g.

[2]Parameters expressed as a percentage of the total eggs laid.

TABLE 5-9. Correlation coefficients (and *P* values) of interrelationships between the prime egg laying sequence length and the average egg laying sequence length for wk 40, wk 44, wk 48, wk 52, wk 56 and wk 60 (n=202)

	Correlation Coefficient (*P* value)					
	Ave. Seq. wk 40	Ave. Seq. wk 44	Ave. Seq. wk 48	Ave. Seq. wk 52	Ave. Seq. wk 56	Ave. Seq. wk 60
Prime Seq.	0.383 (0.0001)	0.273 (0.0001)	0.264 (0.0002)	0.330 (0.0001)	0.336 (0.0001)	0.269 (0.0001)
Ave. Seq. wk 40		0.569 (0.0001)	0.309 (0.0001)	0.404 (0.0001)	0.408 (0.0001)	0.265 (0.0001)
Ave. Seq. wk 44			0.552 (0.0001)	0.317 (0.0001)	0.474 (0.0001)	0.329 (0.0001)
Ave. Seq. wk 48				0.248 (0.0001)	0.539 (0.0001)	0.539 (0.0001)
Ave. Seq. wk 52					0.427 (0.0001)	0.349 (0.0001)
Ave. Seq. wk 56						0.436 (0.0001)

TABLE 5-10. Effect of photostimulation age (19WK or 21WK) on parameters associated with egg production to 61 wk of age (C-Group birds) (mean ± SEM)

	Photostimulation Age	
V ariable	19WK	21WK
Number of birds	99	103
Number of sequences	63.1 ± 1.2[b]	59.8 ± 1.1[a]
Average sequence length	2.85 ± 0.09[a]	3.09 ± 0.09[a]
Prime Sequence length	15.09 ± 1.11[a]	16.79 ± 1.08[a]
Number of Ovulations	178.1 ± 2.2[a]	178.5 ± 2.1[a]
Total eggs	177.8 ± 2.1[a]	178.3 ± 2.1[a]
Settable eggs[1]		
%settable eggs[2]	89.6 ± 0.7[a]	91.3 ± 0.7[a]
total	158.9 ± 2.2[a]	162.4 ± 2.1[a]
Normal eggs		
%normal eggs[2]	96.1 ± 0.6[a]	95.7 ± 0.5[a]
total	170.8 ± 2.3[a]	170.6 ± 2.2[a]
Soft shell eggs		
%soft shell eggs[2]	2.4 ± 0.4[a]	2.7 ± 0.4[a]
total	4.3 ± 0.8[a]	5.0 ± 0.8[a]
Shell-less eggs		
%shelless eggs[2]	0.46 ± 0.09[a]	0.37 ± 0.08[a]
total	0.8 ± 0.1[a]	0.7 ± 0.1[a]
Double yolk eggs		
%double yolk eggs to 61 wk of age[2]	0.17 ± 0.03[a]	0.12 ± 0.03[a]
total to 61 wk of age	0.3 ± 0.1[a]	0.2 ± 0.1[a]
%double yolk eggs to 33 wk of age[2]	0.47 ± 0.11[a]	0.40 ± 0.11[a]
total to 33 wk of age	0.2 ± 0.1[a]	0.2 ± 0.1[a]
Abnormal shell eggs		
%abnormal shelF	0.92 ± 0.18[a]	1.03 ± 0.17[a]
total	1.16 ± 0.3[a]	1.8 ± 0.3[a]

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).
[1]Normal eggs weighing over 52 g.
[2]Parameters expressed as a percentage of the total eggs laid.

TABLE 5-11. Effect of the photostimulation age x growth curve interaction (LOW19, STANDARD19, HIGH19, LOW21, STANDARD21, or HIGH21) on parameters associated with egg production to 61 wk of age (C-Group birds) (mean + SEM)

	Growth Curve x Photostimulation Age					
V ariable	LOW19	STAND19	HIGH19	LOW21	STAND21	HIGH21
No. of birds	35	34	30	33	34	36
Number of sequences	62.9 ± 2.0[a]	62.2 ± 2.0[a]	64.1 ± 2.1[a]	59.7 ± 2.0[a]	59.9 ± 2.0[a]	59.8 ± 1.9[a]
Ave. Seq. length	2.9 ± 0.2[a]	2.8 ± 0.2[a]	2.8 ± 0.2[a]	3.1 ± 0.2[a]	3.0 ± 0.1[a]	3.2 ± 0.2[a]
Prime Seq. length	14.5 ± 1.9[a]	15.4 ± 1.9[a]	15.5 ± 2.0[a]	15.0 ± 1.9[a]	18.2 ± 1.9[a]	17.2 ± 1.8[a]
Number of Ovulations	182.1 ± 3.6[bc]	170.7 ± 3.7[a]	181.6 ± 3.9[bc]	178.9 ± 3.7[abc]	172.6 ± 3.7[ab]	183.9 ± 3.6[c]
Total eggs	181.9 ± 3.6[bc]	170.5 ± 3.7[a]	181.1 ± 3.9[bc]	178.9 ± 3.7[abc]	172.3 ± 3.7[abc]	183.5 ± 3.6[c]
Settable eggs[1]						
%settable[2]	88.1 ± 1.2[a]	91.3 ± 1.2[a]	89.3 ± 1.2[a]	90.4 ± 1.2[a]	92.6 ± 1.2[a]	90.7 ± 1.1[a]
total	159.5 ± 3.7[a]	155.4 ± 3.7[a]	161.8 ± 3.9[a]	161.3 ± 3.8[a]	159.7 ± 3.7[a]	166.3 ± 3.6[a]
Normal eggs						
%normal[2]	95.1 ± 0.9[a]	96.9 ± 1.0[a]	96.3 ± 1.0[a]	94.7 ± 1.0[a]	97.0 ± 1.0[a]	95.5 ± 0.9[a]
total	172.8 ± 3.8[a]	165.2 ± 3.9[a]	174.4 ± 4.1[a]	169.1 ± 3.9[a]	167.3 ± 3.9[a]	175.3 ± 3.8[a]
Soft shell eggs						
%soft shell[2]	3.47 ± 0.70[ab]	1.69 ± 0.70[a]	1.93 ± 0.75[ab]	3.68 ± 0.72[b]	2.01 ± 0.71[ab]	2.52 ± 0.69[ab]
total	6.5 ± 1.3[ab]	2.8 ± 1.3[a]	3.5 ± 1.4[ab]	6.9 ± 1.4[b]	3.4 ± 1.3[ab]	4.6 ± 1.3[ab]
Shell-less eggs						
%shelless[2]	0.39 ± 0.14[a]	0.60 ± 0.15[a]	0.38 ± 0.15[a]	0.42 ± 0.15[a]	0.27 ± 0.15[a]	0.43 ± 0.14[a]
total	0.7 ± 0.2[a]	1.1 ± 0.3[a]	0.7 ± 0.3[a]	0.8 ± 0.3[a]	0.5 ± 0.3[a]	0.8 ± 0.2[a]
Double yolk (DY) eggs						
%DY-61wk[2]	0.11 ± 0.06[ab]	0.14 ± 0.06[abc]	0.28 ± 0.06[c]	0.00 ± 0.06[a]	0.15 ± 0.06[abc]	0.22 ± 0.06[bc]
total DY-61wk	0.2 ± 0.1[ab]	0.3 ± 0.1[abc]	0.5 ± 0.1[c]	0.0 ± 0.1[a]	0.3 ± 0.1[abc]	0.4 ± 0.1[abc]
%DY[2]-33wk	0.35 ± 0.18[ab]	0.23 ± 0.18[ab]	0.82 ± 0.19[c]	0.00 ± 0.19[a]	0.49 ± 0.18[abc]	0.71 ± 0.18[bc]
total DY-33wk	0.2 ± 0.1[ab]	0.1 ± 0.1[a]	0.4 ± 0.1[c]	0.0 ± 0.1[a]	0.2 ± 0.1[ab]	0.4 ± 0.1[bc]
Abnormal shell eggs						
%abnormal shell[2]	0.97 ± 0.30[a]	0.71 ± 0.30[a]	1.09 ± 0.32[a]	1.23 ± 0.31[a]	0.53 ± 0.30[a]	1.33 ± 0.30[a]
total	1.7 ± 0.5[a]	1.1 ± 0.5[a]	2.0 ± 0.6[a]	2.2 ± 0.5[a]	0.9 ± 0.5[a]	2.4 ± 0.5[a]

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).

[1]Normal eggs weighing over 52 g.

[2]Parameters expressed as a percentage of the total eggs laid.

NB No significant interaction effect of growth curve x photostimulation age for any variable.

TABLE 5-12. Effect of growth curve (LOW, STANDARD or HIGH) on average weekly egg weights (C-group birds) (mean ± SEM)

Time Period (age of birds)	Growth Curve		
	LOW	STANDARD	HIGH
wk 27 - wk 30	55.3 ± 0.3[a]	55.7 ± 0.3[ab]	56.4 ± 0.3[b]
wk 31 - wk 34	60.3 ± 0.3[a]	60.8 ± 0.3[ab]	61.5 ± 0.3[b]
wk 35 - wk 38	63.3 ± 0.3[a]	63.9 ± 0.3[a]	64.9 ± 0.3[b]
wk 39 - wk42	65.4 ± 0.3[a]	65.8 ± 0.3[a]	66.5 ± 0.3[b]
wk 43 - wk 46	66.3 ± 0.3[a]	67.6 ± 0.3[b]	67.3 ± 0.3[b]
wk 47 - wk 50	67.0 ± 0.3[a]	68.0 ± 0.3[b]	68.4 ± 0.3[b]
wk 51 - wk 54	67.9 ± 0.3[a]	68.4 ± 0.3[ab]	69.1 ± 0.3[b]
wk 55 - wk 58	67.5 ± 0.3[a]	68.6 ± 0.3[b]	69.4 ± 0.3[b]
wk 59 - wk 61	69.4 ± 0.4[a]	70.0 ± 0.4[ab]	71.1 ± 0.4[b]

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).

TABLE 5-13. Effect of photostimulation age (19WK or 21WK) on average weekly egg weights (C-group birds) (mean ± SEM)

	Photostimulation Age	
Time Period (age of birds)	19WK	21WK
wk 27 - wk 30	55.5 ± 0.2[a]	56.0 ± 0.2[a]
wk 31 - wk 34	60.6 ± 0.2[a]	61.1 ± 0.2[a]
wk 35 - wk 38	63.7 ± 0.2[a]	64.3 ± 0.2[b]
wk 39 - wk42	65.8 ± 0.2[a]	66.0 ± 0.2[a]
wk 43 - wk 46	67.1 ± 0.2[a]	67.1 ± 0.2[a]
wk 47 - wk 50	67.7 ± 0.2[a]	67.9 ± 0.2[a]
wk 51 - wk 54	68.2 ± 0.2[a]	68.7 ± 0.2[a]
wk 55 - wk 58	68.4 ± 0.3[a]	68.7 ± 0.3[a]
wk 59 - wk 61	70.1 ± 0.4[a]	70.3 ± 0.3[a]

[a,b] Means within a row with no common superscript differ significantly ($P < 0.05$).

TABLE 5-14. Effect of the growth curve x photostimulation age interaction (LOW19, STANDARD19, HIGH19, LOW21, STANDARD21, or HIGH21) on average weekly egg weights (C-group birds) (mean_+ SEM)

Time Period (age of birds)	Growth Curve x Photostimulation Age					
	LOW19	STAND19	HIGH19	LOW21	STAND21	HIGH21
wk 27 - wk 30*	54.6 ± 0.4^{a}	56.1 ± 0.4^{bc}	55.9 ± 0.4^{bc}	55.9 ± 0.4^{bc}	55.3 ± 0.4^{ab}	56.9 ± 0.4^{c}
wk 31 - wk 34*	59.5 ± 0.4^{a}	61.1 ± 0.4^{bc}	61.2 ± 0.4^{bc}	61.2 ± 0.4^{bc}	60.4 ± 0.4^{ab}	61.8 ± 0.4^{c}
wk 35 - wk 38	62.7 ± 0.3^{a}	63.9 ± 0.4^{b}	64.5 ± 0.4^{bc}	63.8 ± 0.4^{b}	63.9 ± 0.4^{b}	65.2 ± 0.3^{c}
wk 39 - wk42	65.3 ± 0.4^{b}	65.9 ± 0.4^{ab}	66.3 ± 0.4^{b}	65.7 ± 0.4^{ab}	65.7 ± 0.4^{ab}	66.7 ± 0.4^{b}
wk 43 - wk 46	66.2 ± 0.4^{a}	68.0 ± 0.4^{c}	67.1 ± 0.4^{abc}	66.5 ± 0.4^{ab}	67.2 ± 0.4^{ab}	67.5 ± 0.4^{bc}
wk 47 - wk 50	66.7 ± 0.4^{a}	68.0 ± 0.4^{bc}	68.3 ± 0.4^{bc}	67.2 ± 0.4^{ab}	68.0 ± 0.4^{bc}	68.5 ± 0.4^{c}
wk 51 - wk 54	67.6 ± 0.4^{a}	68.4 ± 0.4^{a}	68.7 ± 0.4^{ab}	68.2 ± 0.4^{a}	68.3 ± 0.5^{a}	69.6 ± 0.4^{a}
wk 55 - wk 58	66.9 ± 0.5^{a}	68.8 ± 0.5^{bc}	69.3 ± 0.5^{bc}	68.1 ± 0.5^{c}	68.4 ± 0.5^{bc}	69.4 ± 0.5^{c}
wk 59 - wk 61	69.1 ± 0.6^{a}	69.9 ± 0.6^{ab}	71.3 ± 0.6^{b}	69.8 ± 0.6^{ab}	70.2 ± 0.6^{ab}	70.9 ± 0.6^{b}

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).

* Indicates a significant interaction effect of Growth curve x photostimulation age for the variable.

TABLE 5-15. Effect of growth curve (LOW, STANDARD or HIGH) on incubation traits (mean ± SEM)

	Growth Curve		
Variable	LOW	STANDARD	HIGH
Total eggs set	2262	2226	2195
Fertility			
% of eggs set	90.43 ± 0.37[a]	90.97 ± 0.37[a]	90.47 ± 0.37[a]
Hatchability			
% of eggs set	79.11 ± 0.51[a]	82.67 ± 0.51[b]	80.22 ± 0.52[a]
% of fertile eggs set	86.96 ± 0.43[a]	90.45 ± 0.43[c]	88.31 ± 0.44[b]
Stage-1[1]			
% of eggs set	4.54 ± 0.22[c]	2.77 ± 0.22[a]	3.48 ± 0.22[b]
% of non-hatched eggs	21.12 ± 0.98[b]	16.45 ± 1.03[a]	18.13 ± 1.01[a]
Stage-2[2]			
% of eggs set	3.21 ± 0.19[b]	2.56 ± 0.19[a]	3.03 ± 0.19[ab]
% of non-hatched eggs	15.46 ± 0.91[a]	15.35 ± 0.96[a]	15.42 ± 0.94[a]
Stage-3[3]			
%of eggs set	3.01 ± 0.19[b]	2.21 ± 0.19[a]	2.85 ± 0.19[b]
% of non-hatched eggs	14.42 ± 0.89[a]	13.44 ± 0.94[a]	14.99 ± 0.92[a]
Dead in Shell			
% of eggs set	0.15 ± 0.05[a]	0.22 ± 0.05[ab]	0.31 ± 0.05[b]
% of non-hatched eggs	0.95 ± 0.28[a]	1.39 ± 0.30[a]	1.37 ± 0.29[a]
Cull			
% of eggs set	0.41 ± 0.08[a]	0.53 ± 0.08[a]	0.58 ± 0.08[a]
% of non-hatched eggs	2.21 ± 0.42[a]	3.32 ± 0.44[a]	2.87 ± 0.44[a]

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).
Stage-1[1] = mortality occuring during 0 - 7 d incubation.
Stage-2[2] = mortality occuring during 7 - 14 d incubation.
Stage-3[3] = mortality occuring after 14 d incubation.

TABLE 5-16. Effect of photostimulation age (19WK or 21WK) on incubation traits (mean ± SEM)

	Photostimulation Age	
Variable	19WK	21WK
Total eggs set	3259	3424
Fertility		
% of eggs set	90.80 ± 0.31[a]	90.44 ± 0.30[a]
Hatchability		
% of eggs set	81.03 ± 0.42[a]	80.31 ± 0.41[a]
% of fertile eggs set	88.74 ± 0.36[a]	88.41 ± 0.35[a]
Stage-1[1]		
% of eggs set	3.53 ± 0.18[a]	3.66 ± 0.17[a]
% of non-hatched eggs	18.54 ± 0.84[a]	18.60 ± 0.81[a]
Stage-2[2]		
% of eggs set	3.07 ± 0.16[a]	2.80 ± 0.15[a]
% of non-hatched eggs	16.28 ± 0.78[a]	14.54 ± 0.75[a]
Stage-3[3]		
%of eggs set	2.48 ± 0.16[a]	2.90 ± 0.15[a]
% of non-hatched eggs	13.28 ± 0.76[a]	15.29 ± 0.74[a]
Dead in Shell		
% of eggs set	0.18 ± 0.04[a]	0.28 ± 0.04[a]
% of non-hatched eggs	0.90 ± 0.24[a]	1.58 ± 0.23[a]
Cull		
% of eggs set	0.52 ± 0.07[a]	0.49 ± 0.07[a]
% of non-hatched eggs	2.59 ± 0.36[a]	3.01 ± 0.35[a]

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).
Stage-1[1] = mortality occuring during 0 - 7 d incubation.
Stage-2[2] = mortality occuring during 7 - 14 d incubation.
Stage-3[3] = mortality occuring after 14 d incubation.

TABLE 5-17. Effect of the growth curve x photostimulation age interaction (LOW19, STANDARD19, HIGH19, LOW21, STANDARD21, or HIGH21) on incubation traits (mean + SEM)

	Growth Curve x Photostimulation Age					
Variable	LOW19	STAND19	HIGH19	LOW21	STAND21	HIGH21
Total eggs set	1170	1094	995	1092	1132	1200
Fertility						
% of eggs set*	91.02 ± 0.51^{ab}	90.27 ± 0.53^{ab}	91.11 ± 0.55^{ab}	89.84 ± 0.53^{a}	91.66 ± 0.52^{b}	89.84 ± 0.51^{a}
Hatchability						
% of eggs set*	80.47 ± 0.71^{bc}	81.45 ± 0.73^{c}	81.15 ± 0.76^{bc}	77.75 ± 0.73^{a}	83.90 ± 0.72^{d}	79.30 ± 0.70^{a}
% of fertile eggs set*	87.95 ± 0.60^{b}	89.61 ± 0.62^{bc}	88.65 ± 0.65^{b}	85.98 ± 0.62^{a}	91.30 ± 0.61^{c}	87.96 ± 0.59^{b}
Stage-1[1]						
% of eggs set*	3.84 ± 0.30^{b}	3.08 ± 0.31^{ab}	3.67 ± 0.32^{b}	5.23 ± 0.31^{c}	2.46 ± 0.30^{a}	3.29 ± 0.29^{b}
% of non-hatched eggs*	18.95 ± 1.40^{a}	16.74 ± 1.46^{a}	19.92 ± 1.51^{ab}	23.29 ± 1.37^{b}	16.17 ± 1.46^{a}	16.34 ± 1.36^{a}
Stage-2[2]						
% of eggs set	3.08 ± 0.27^{b}	2.97 ± 0.27^{b}	3.14 ± 0.29^{b}	3.33 ± 0.27^{b}	2.15 ± 0.27^{a}	2.91 ± 0.26^{b}
% of non-hatched eggs	15.21 ± 1.29^{a}	16.59 ± 1.35^{a}	17.04 ± 1.39^{a}	15.71 ± 1.27^{a}	14.11 ± 1.35^{a}	13.79 ± 1.26^{a}
Stage-3[3]						
%of eggs set	3.09 ± 0.26^{c}	2.06 ± 0.27^{a}	2.30 ± 0.28^{ab}	2.93 ± 0.27^{bc}	2.36 ± 0.26^{ab}	3.41 ± 0.26^{c}
% of non-hatched eggs*	15.38 ± 1.27^{bc}	11.44 ± 1.33^{a}	13.01 ± 1.37^{ab}	13.46 ± 1.25^{c}	15.45 ± 1.33^{bc}	16.96 ± 1.23^{a}
Dead in Shell						
% of eggs set	0.09 ± 0.07^{a}	0.20 ± 0.07^{a}	0.25 ± 0.08^{a}	0.22 ± 0.07^{a}	0.25 ± 0.07^{a}	0.37 ± 0.07^{a}
% of non-hatched eggs	0.45 ± 0.40^{a}	1.12 ± 0.42^{ab}	1.13 ± 0.43^{ab}	1.46 ± 0.39^{ab}	1.66 ± 0.42^{b}	1.62 ± 0.39^{b}
Cull						
% of eggs set	0.45 ± 0.11^{a}	0.52 ± 0.12^{a}	0.61 ± 0.12^{a}	0.38 ± 0.12^{a}	0.54 ± 0.11^{a}	0.56 ± 0.11^{a}
% of non-hatched eggs	2.39 ± 0.60^{a}	2.50 ± 0.63^{a}	2.87 ± 0.65^{a}	2.04 ± 0.59^{a}	4.13 ± 0.63^{a}	2.88 ± 0.59^{a}

^{a,b,c} Means within a row with no common superscript differ significantly ($P < 0.05$).

* Indicates a significant interaction effect of growth curve x photostimulation age for the variable.

Stage-1[1] = mortality occuring during 0 - 7 d incubation.

Stage-2[2] = mortality occuring during 7 - 14 d incubation.

Stage-3[3] = mortality occuring after 14 d incubation.

Table 5-18. The effect of growth curve (LOW, STANDARD or HIGH) on numbers of chicks produced and feed consumption per chick in terms of each of the three different diets and in terms of total feed (mean ± SEM)

	Growth Curve		
Variable	LOW	STANDARD	HIGH
Number of hens	68	68	66
Chicks[1]	127.7 ± 3.4[a]	130.7 ± 3.4[a]	132.1 ± 3.4[a]
Starter Feed[2]			
Consumed (g)	579	576	579
Consumed per Chick (g/chick)	4.9 ± 0.2[a]	4.7 ± 0.2[a]	4.6 ± 0.2[a]
Grower Feed[3]			
Consumed (g)	6204	6827	7358
Consumed per chick (g/chick)	52.5 ± 2.1[a]	55.5 ± 2.1[a]	58.3 ± 2.1[a]
Breeder Feed[4]			
Consumed (g)	37489	38406	41115
Consumed per chick (g/chick)	317.2 ± 12.1[a]	312.5 ± 11.9[a]	325.6 ± 12.1[a]
Total feed			
Consumed (g)	44272	45809	49051
Consumed per chick (g/chick)	374.6 ± 14.3[a]	372.7 ± 14.1[a]	388.4 ± 14.4[a]

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).
Chicks[1] = total settable eggs over 52 g laid by a hen multiplied by the average hatchability of setable eggs for that hen.
Starter feed[2] provided from 0 to 3 wk of age.
Grower feed[3] provided from 3 to 20 wk of age.
Breeder feed[4] provided from 20 to 61 wk of age.

Table 5-19. The effect of photostimulation age (19WK or 21WK) on numbers of chicks produced and feed consumption per chick in terms of each of the three different diets and in terms of total feed (mean ± SEM)

	Photostimulation Age	
Variable	19WK	21WK
Number of hens	99	103
Chicks[1]	129.3 ± 2.8[a]	131.0 ± 2.8[a]
Starter Feed[2]		
Consumed (g)	578	578
Consumed per chick (g/chick)	4.8 ± 0.2[a]	4.7 ± 0.1[a]
Grower Feed[3]		
Consumed (g)	6796	6796
Consumed per chick (g/chick)	56.2 ± 1.7[a]	54.7 ± 1.7[a]
Breeder Feed[4]		
Consumed (g)	39051	39034
Consumed per chick (g/chick)	323.1 ± 9.9[a]	313.7 ± 9.7[a]
Total feed		
Consumed (g)	46425	46409
Consumed per chick (g/chick)	384.1± 11.8[a]	373.1 ± 11.5[a]

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).
Chicks[1] = total settable eggs weighing over 52 g laid by a hen multiplied by the hatchability of settable eggs for that hen.
Starter feed[2] provided from 0 to 3 wk of age.
Grower feed[3] provided from 3 to 20 wk of age.
Breeder feed[4] provided from 20 to 61 wk of age.

Table 5-20. The effect of the growth curve x photostimulation age interaction (LOW19, STANDARD19, HIGH19, LOW21, STANDARD21, or HIGH21) on numbers of chicks produced and feed consumption per chick in terms of each of the three different diets and in terms of total feed (mean ± SEM)

	Growth Curve x Photostimulation Age					
Variable	LOW19	STAND19	HIGH19	LOW21	STAND21	HIGH21
Number of hens	35	34	30	33	34	36
Chicks[1]	129.2 ± 4.8[a]	127.1 ± 4.8[a]	131.7 ± 5.1[a]	126.2 ± 4.9[a]	134.2 ± 4.8[a]	132.6 ± 4.6[a]
Starter Feed[2]						
Consumed (g)	579	576	579	579	576	579
Consumed per Chick (g/chick)	4.9 ± 0.3[a]	4.9 ± 0.3[a]	4.6 ± 0.3[a]	4.9 ± 0.3[a]	4.4 ± 0.3[a]	4.6 ± 0.3[a]
Grower Feed[3]						
Consumed (g)	6204	6827	7358	6204	6827	7358
Consumed per chick (g/chick)	52.3 ± 2.9[a]	58.6 ± 2.9[a]	57.8 ± 3.1[a]	52.7 ± 3.0[a]	55.5 ± 2.9[a]	58.8 ± 2.8[a]
Breeder Feed[4]						
Consumed (g)	37513	38437	41202	37464	38374	41027
Consumed per chick (g/chick)	316.1 ± 16.8[a]	329.7 ± 16.8[a]	323.5 ± 17.9[a]	318.4 ± 17.3[a]	295.2 ± 16.8[a]	327.6 ± 16.3[a]
Total feed						
Consumed (g)	44296	45840	49139	44247	45777	48964
Consumed per chick (g/chick)	373.3 ± 19.9[a]	393.3 ± 19.9[a]	385.9 ± 21.2[a]	376.0 ± 20.6[a]	352.2 ± 19.9[a]	391.0 ± 19.4[a]

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).

Chicks[1] = total settable eggs weighing over 52 g laid by a hen multiplied by the average hatchability of settable eggs for that hen. Starter feed[2] provided from 0 to 3 wk of age. Grower feed[3] provided from 3 to 20 wk of age. Breeder feed[4] provided from 20 to 61 wk of age. NB no interaction effect of growth curve x photostimulation age for any variable.

TABLE 5-21. Effect of growth curve (LOW, STANDARD or HIGH) on carcass traits and ovarian morphology at 61 wk of age (C-Group birds) (mean ± SEM)

	Growth Curve		
Variable	LOW	STANDARD	HIGH
Number of birds	67	68	66
Average BW, g	3415 ± 38[a]	3724 ± 37[b]	3947 ± 38[c]
Shank length, mm	104.9 ± 0.4[a]	106.9 ± 0.4[b]	107.9 ± 0.4[b]
Liver			
%BW	1.43 ± 0.03[b]	1.34 ± 0.03[a]	1.42 ± 0.03[ab]
g	48.7 ± 1.1[a]	49.7 ± 1.1[a]	55.7 ± 1.1[b]
Breast			
%BW	15.31 ± 0.15[a]	15.33 ± 0.15[a]	15.20 ± 0.16[a]
g	523.2 ± 8.4[a]	571.1 ± 8.3[b]	599.6 ± 8.5[c]
Abdominal fatpad			
%BW	4.46 ± 0.19[a]	5.06 ± 0.18[b]	5.69 ± 0.19[c]
g	154.6 ± 8.0[a]	190.8 ± 7.9[b]	226.2 ± 8.1[c]
Oviduct			
%BW	2.01 ± 0.06[b]	1.80 ± 0.06[a]	1.75 ± 0.06[a]
g	67.9 ± 1.8[a]	65.9 ± 1.8[a]	68.4 ± 1.9[a]
Ovary			
%BW	1.15 ± 0.05[a]	1.03 ± 0.05[a]	1.14 ± 0.05[a]
g	39.2 ± 1.6[a]	37.7 ± 1.6[a]	44.7 ± 1.6[b]
Stroma			
%BW	0.29 ± 0.01[b]	0.25 ± 0.01[a]	0.26 ± 0.01[a]
g	9.6 ± 0.3[a]	9.1 ± 0.3[a]	90.0 ± 0.3[a]
Number of SYF[1]	12.0 ± 0.7[ab]	10.2 ± 0.7[a]	12.2 ± 0.7[b]
Number of LYF[2]	5.1 ± 0.1[a]	4.9 ± 0.2[a]	5.3 ± 0.2[a]
Percent of LYF within 1 g (%)	2.43 ± 2.21[a]	1.70 ± 2.23[a]	7.39 ± 2.27[a]

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).
SYF [1] = small yellow follicles.
LYF [2] = large yellow follicles.

TABLE 5-22. Effect of photostimulation age (19WK and 21WK) on carcass traits and ovarian morphology at 61 wk of age (C-Group birds) (mean ± SEM)

	Photostimulation Age	
Variable	19WK	21WK
Number of birds	99	102
BW, g	3731 ± 31[a]	3660 ± 30[a]
Shank length, mm	106.7 ± 0.3[a]	106.5 ± 0.3[a]
Liver		
%BW	1.42 ± 0.02[a]	1.37 ± 0.02[a]
g	52.6 ± 0.9[b]	50.0 ± 0.9[a]
Breast		
%BW	15.26 ± 0.13[a]	15.30 ± 1.3[a]
g	569.1 ± 6.9[a]	560.1 ± 6.8[a]
Abdominal fatpad		
%BW	5.21 ± 0.15[a]	4.92 ± 0.15[a]
g	197.5 ± 6.6[a]	183.5 ± 6.6[a]
Oviduct		
%BW	1.78 ± 0.05[a]	1.93 ± 0.05[b]
g	65.5 ± 1.5[a]	69.4 ± 1.5[a]
Ovary		
%BW	1.13 ± 0.04[a]	1.09 ± 0.04[a]
g	41.9 ± 1.3[a]	39.2 ± 1.3[a]
Stroma		
%BW	0.26 ± 0.01[a]	0.27 ± 0.01[a]
g	9.5 ± 0.2[a]	9.7 ± 0.2[a]
Number of SYF[1]	10.9 ± 0.6[a]	12.0 ± 0.6[a]
Number of LYF[2]	5.2 ± 0.1[a]	5.0 ± 0.1[a]
Percent of LYF within 1 g (%)	3.16 ± 1.86[a]	4.52 ± 1.80[a]

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).
SYF [1] = small yellow follicles.
LYF [2] = large yellow follicles.

TABLE 5-23. Effect of growth curve x photostimulation age interaction (LOW19, STANDARD19, HIGH19, LOW21, STANDARD21,or HIGH21) on carcass traits and ovarian morphology at 61 wk of age (mean + SEM)

	Growth Curve x Photostimulation Age					
Variable	LOW19	STAND19	HIGH19	LOW21	STAND21	HIGH21
no. of birds	35	34	30	32	34	36
BW, g	3453 ± 58^{a}	3744 ± 53^{b}	3996 ± 56^{c}	3378 ± 57^{a}	3703 ± 53^{b}	3897 ± 51^{c}
Shank length, mm	104.7 ± 0.6^{a}	107.0 ± 0.6^{c}	108.4 ± 0.6^{c}	105.2 ± 0.6^{ab}	106.8 ± 0.6^{bc}	107.4 ± 0.6^{c}
Liver						
%BW	1.47 ± 0.04^{b}	1.34 ± 0.04^{a}	1.44 ± 0.04^{ab}	1.38 ± 0.04^{ab}	1.34 ± 0.04^{ab}	1.39 ± 0.04^{ab}
g	50.9 ± 1.5^{bc}	49.9 ± 1.6^{ab}	57.1 ± 1.7^{d}	46.4 ± 1.6^{ab}	49.4 ± 1.6^{ab}	54.2 ± 1.5^{cd}
Breast						
%BW*	15.39 ± 0.21^{ab}	15.54 ± 0.22^{b}	14.89 ± 0.23^{a}	15.22 ± 0.22^{ab}	15.13 ± 0.22^{ab}	15.55 ± 0.21^{b}
g	531.3 ± 11.6^{ab}	582.1 ± 11.8^{cd}	593.8 ± 12.5^{cd}	515.1 ± 12.1^{a}	559.9 ± 11.8^{bc}	605.3 ± 11.4^{d}
Abdom. fat.						
%BW	4.57 ± 0.26^{ab}	4.90 ± 0.26^{ab}	6.17 ± 0.28^{c}	4.34 ± 0.27^{a}	5.21 ± 0.26^{b}	5.22 ± 0.25^{b}
g	159.5 ± 11.0^{ab}	185.6 ± 11.2^{bc}	247.5 ± 11.9^{d}	149.7 ± 11.5^{a}	196.0 ± 11.2^{c}	204.9 ± 10.9^{c}
Oviduct						
%BW	1.89 ± 0.08^{a}	1.75 ± 0.08^{a}	1.70 ± 0.09^{a}	2.13 ± 0.08^{b}	1.86 ± 0.08^{a}	1.80 ± 0.08^{a}
g	64.8 ± 2.6^{a}	64.1 ± 2.6^{a}	67.5 ± 2.8^{a}	71.1 ± 2.7^{a}	67.8 ± 2.6^{a}	69.3 ± 2.5^{a}
Ovary						
%BW	1.18 ± 0.06^{a}	1.04 ± 0.06^{a}	1.19 ± 0.07^{a}	1.15 ± 0.07^{a}	1.02 ± 0.06^{a}	1.09 ± 0.06^{a}
g	39.9 ± 2.2^{a}	38.4 ± 2.3^{a}	47.4 ± 2.4^{a}	38.6 ± 2.4^{a}	37.0 ± 2.3^{a}	41.9 ± 2.2^{a}
Stroma						
%BW	0.27 ± 0.01^{ab}	0.25 ± 0.01^{a}	0.25 ± 0.01^{a}	0.30 ± 0.01^{b}	0.25 ± 0.01^{a}	0.26 ± 0.01^{a}
g	9.3 ± 0.4^{a}	9.2 ± 0.4^{a}	9.9 ± 0.4^{a}	9.9 ± 0.4^{a}	9.0 ± 0.4^{a}	10.0 ± 0.3^{a}
no. SYF[1]	9.9 ± 1.0^{a}	10.3 ± 1.0^{a}	12.6 ± 1.0^{ab}	14.1 ± 1.0^{b}	10.0 ± 1.0^{a}	11.8 ± 1.0^{ab}
no. LYF[2]	5.2 ± 0.2^{a}	4.8 ± 0.2^{a}	5.6 ± 0.2^{a}	5.0 ± 0.2^{a}	5.0 ± 0.2^{a}	5.1 ± 0.2^{c}
Percent of LYF within 1 g (%)	1.73 ± 3.11^{a}	2.37 ± 3.21^{a}	5.39 ± 3.38^{a}	3.13 ± 3.16^{a}	1.04 ± 3.16^{a}	9.39 ± 3.02^{a}

[a,b,c] Means within a row with no common superscript differ significantly ($P < 0.05$).

* Indicates a significant interaction effect of growth curve x photostimulation age for the variable.

SYF [1] = small yellow follicles.

LYF [2] = large yellow follicles.

TABLE 5-24. Mean values of BW, ovary weight, large yellow follicle numbers (LYF), small yellow follicle numbers (SYF), and percent of LYF within 1 g (Per.) at 61 wk of age from 201 broiler breeder hens (100%), the upper 50% (n=100), the lower 50% (n=100), the upper 25% (n=50) and the lower 25% (n=50) of the flock sorted on the basis of either total egg numbers or prime sequence length

Sort Basis	Variable	100% of flock	upper 50% of flock	lower 50% of flock	upper 25% of flock	lower 25% of flock
Total numbers of eggs produced	Total eggs	178.0 ± 1.5	194.8 ± 1.4[b]	161.2 ± 1.4[a]	204.0 ± 1.7[b]	149.7 ± 1.7[a]
	Prime Seq., d	15.98 ± 0.77	20.8 ± 1.0[b]	11.2 ± 1.0[a]	25.8 ± 1.5[b]	10.1 ± 1.5[a]
	Body weight, g	3693 ± 26	3553 ± 35[a]	3833 ± 35[b]	3558 ± 49[a]	3969 ± 49[b]
	Ovary weight, g	40.4 ± 0.96	43.3 ± 1.3[b]	37.6 ± 1.3[a]	44.3 ± 2.0[b]	36.4 ± 2.0[a]
	LYF	5.1 ± 0.1	5.3 ± 0.1[b]	4.9 ± 0.1[a]	5.5 ± 0.2[b]	5.0 ± 0.2[a]
	SYF	11.4 ± 0.4	11.8 ± 0.6[a]	11.0 ± 0.6[a]	11.1 ± 0.9[a]	11.3 ± 0.9[a]
	Per, %	4.43± 1.11	1.97 ± 1.79[a]	6.02 ± 1.87[b]	1.26 ± 1.71[a]	6.54 ± 1.82[b]
Prime sequence length	Total eggs	178.0 ± 1.5	187.2 ± 2.0[b]	168.7 ± 2.0[a]	194.8 ± 2.3[b]	165.0 ± 2.3[a]
	Prime Seq., d	15.98 ± 0.77	23.3 ± 0.8[b]	8.7 ± 0.8[a]	31.48 ± 1.11[b]	6.78 ± 1.11[a]
	Body weight, g	3693 ± 26	3639 ± 37[a]	3750 ± 37[b]	3630 ± 53[a]	3766 ± 53[a]
	Ovary weight, g	40.4 ± 0.96	43.7 ± 1.3[b]	37.2 ± 1.3[a]	43.7 ± 1.8[b]	35.2 ± 1.8[a]
	LYF	5.1 ± 0.1	5.3 ± 0.1[b]	4.8 ± 0.1[a]	5.3 ± 0.2[b]	4.7 ± 0.2[a]
	SYF	11.4 ± 0.4	11.3 ± 0.6[a]	11.5 ± 0.6[a]	11.3 ± 0.9[a]	11.3 ± 0.9[a]
	Per, %	4.43 ± 1.11	1.28 ± 1.79[a]	6.30 ± 1.83[a]	1.98 ± 3.39[a]	8.84 ± 3.47[a]

[a,b] Means compared between either the upper 50% of the flock and the lower 50% of the flock or between the upper 25% of the flock and the lower 25% of the flock with different superscripts are significantly different ($P < 0.05$).

TABLE 5-25. Correlation coefficients (and *P* values) of interrelationships between various carcass and ovarian traits and production parameters in 201 61 wk old hens

	Correlation Coefficient (*P* value)												
	Breast weight	Fatpad weight	Liver weight	Oviduct weight	Ovary weight	no. SYF[1]	no. LYF[2]	% of LYF within 1 g	Total Eggs	Defect Eggs	Prime Seq.	Ave. Seq.	Chicks
Body Weight	0.762 (0.0001)	0.708 (0.0001)	0.413 (0.0001)	-0.302 (0.0001)	-0.016 (0.8185)	-0.116 (0.1029)	0.043 (0.5472)	0.220 (0.0022)	-0.370 (0.0001)	-0.115 (0.0348)	-0.156 (0.0268)	-0.268 (0.0001)	-0.237 (0.0007)
Breast weight		0.304 (0.0001)	0.191 (0.0067)	-0.308 (0.0001)	-0.107 (0.1321)	-0.118 (0.0992)	-0.058 (0.4197)	0.226 (0.0017)	-0.387 (0.0001)	-0.057 (0.4187)	-0.172 (0.0149)	-0.210 (0.0028)	-0.221 (0.0017)
Fatpad weight			0.461 (0.0001)	-0.162 (0.0215)	0.061 (0.3871)	-0.103 (0.1478)	0.076 (0.2910)	0.101 (0.1634)	-0.208 (0.0030)	-0.172 (0.0145)	-0.054 (0.4484)	-0.235 (0.0008)	-0.107 (0.1319)
Liver weight				-0.031 (0.6589)	0.216 (0.0020)	-0.0056 (0.9382)	0.171 (0.0167)	0.108 (0.1377)	-0.112 (0.1124)	0.006 (0.9354)	-0.053 (0.4563)	-0.172 (0.0146)	-0.167 (0.0184)
Oviduct weight					0.536 (0.0001)	0.126 (0.0778)	0.429 (0.0001)	-0.268 (0.0002)	0.312 (0.0001)	0.001 (0.9919)	0.114 (0.1084)	0.177 (0.0119)	0.286 (0.0001)
Ovary weight						0.1533 (0.0318)	0.762 (0.0001)	-0.099 (0.1717)	0.283 (0.0001)	-0.064 (0.3683)	0.198 (0.0049)	0.238 (0.0007)	0.219 (0.0019)
no. SYF[1]							0.019 (0.7972)	-0.051 (0.4826)	0.020 (0.7852)	0.015 (0.8335)	-0.030 (0.6674)	0.031 (0.6638)	0.019 (0.7969)
no. LYF[2]								-0.021 (0.7776)	0.193 (0.0070)	-0.022 (0.7560)	0.146 (0.0416)	0.243 (0.0006)	0.063 (0.3843)
% of LYF within 1 g									-0.151 (0.0372)	0.265 (0.0002)	-0.101 (0.1655)	-0.089 (0.2197)	-0.269 (0.0002)
Total Eggs										0.139 (0.0484)	0.485 (0.0001)	0.672 (0.0001)	0.546 (0.0001)
Defect Eggs											-0.028 (0.6964)	-0.069 (0.3304)	-0.560 (0.0001)
Prime Seq.												0.665 (0.0001)	0.328 (0.0001)
Ave. Seq.													0.517 (0.0001)

SYF[1] = small yellow follicles. LYF[2] = large yellow follicles.

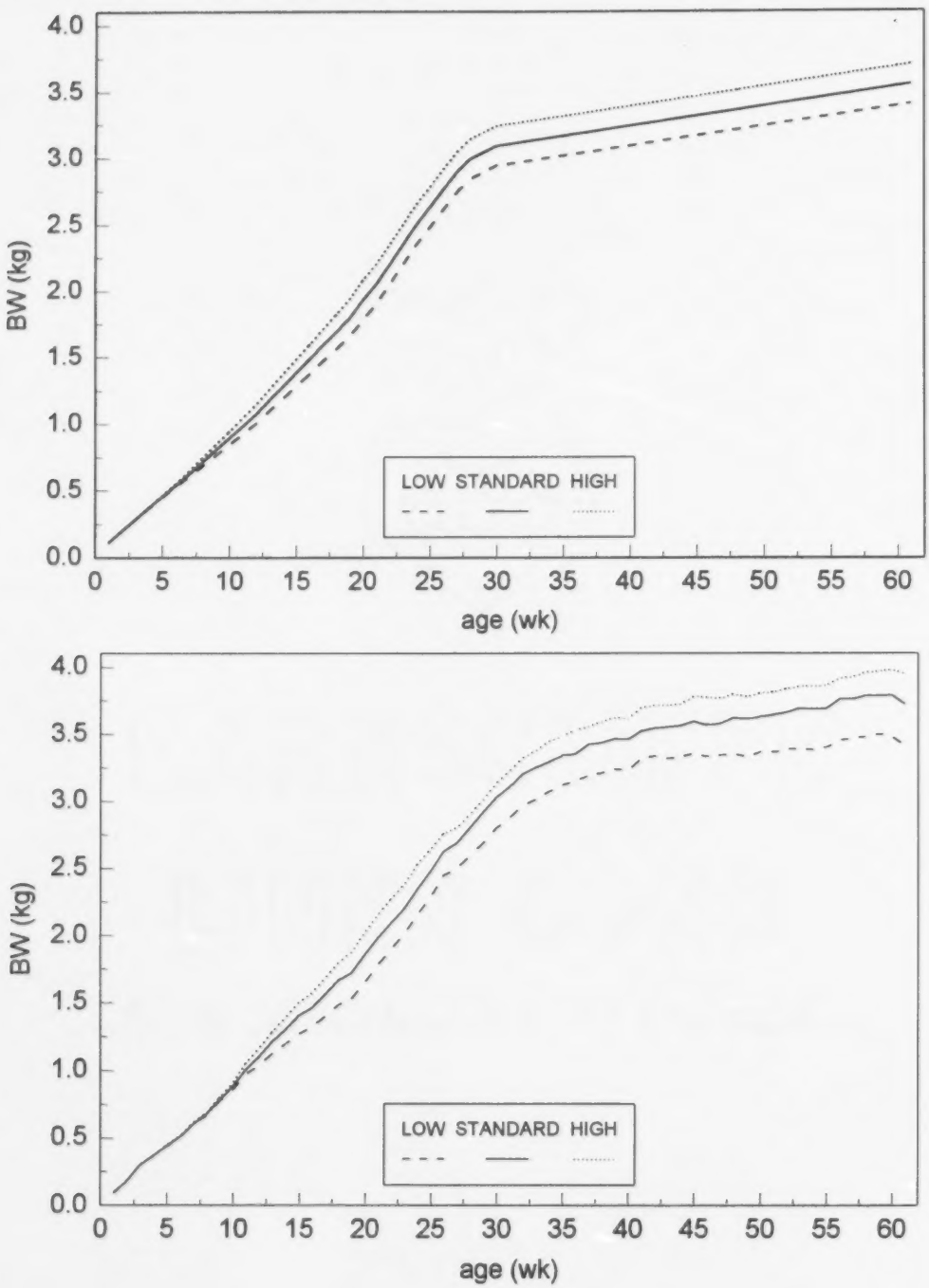

FIGURE 5-1. Upper panel: Body weight targets for the main effect of growth curve (LOW, STANDARD or HIGH) from 1 to 61 wk of age. Lower panel: Actual weekly BW of all birds up to 18 wk of age and only the C-Group birds from 18 wk of age through to 61 wk of age.

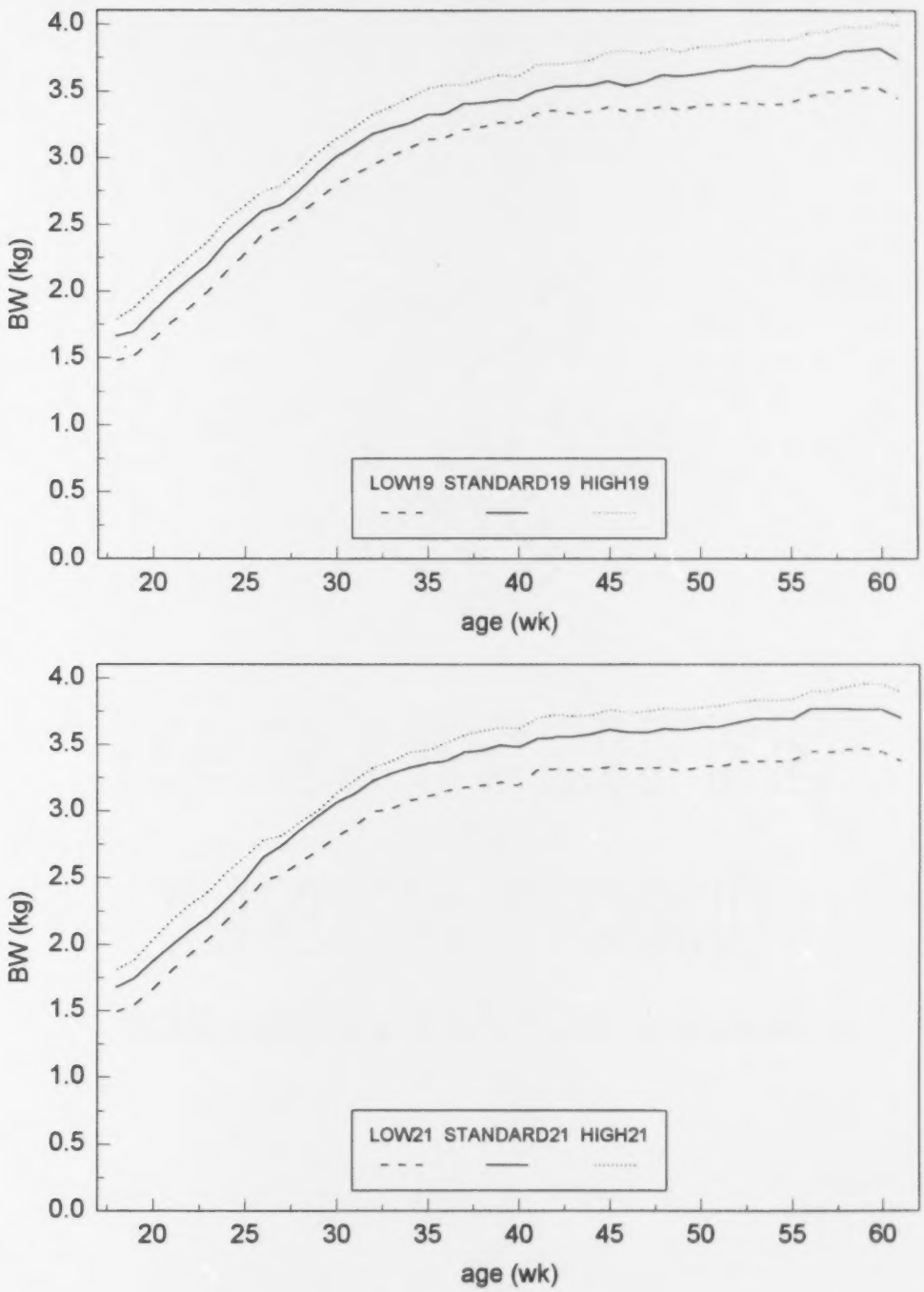

FIGURE 5-2. Actual weekly BW of the C-Group birds from 18 to 61 wk of age for the interaction effect. The interaction treatments LOW19, STANDARD19 and HIGH19 are shown in upper panel and the interaction treatments LOW21, STANDARD21 and HIGH21 are shown in lower panel.

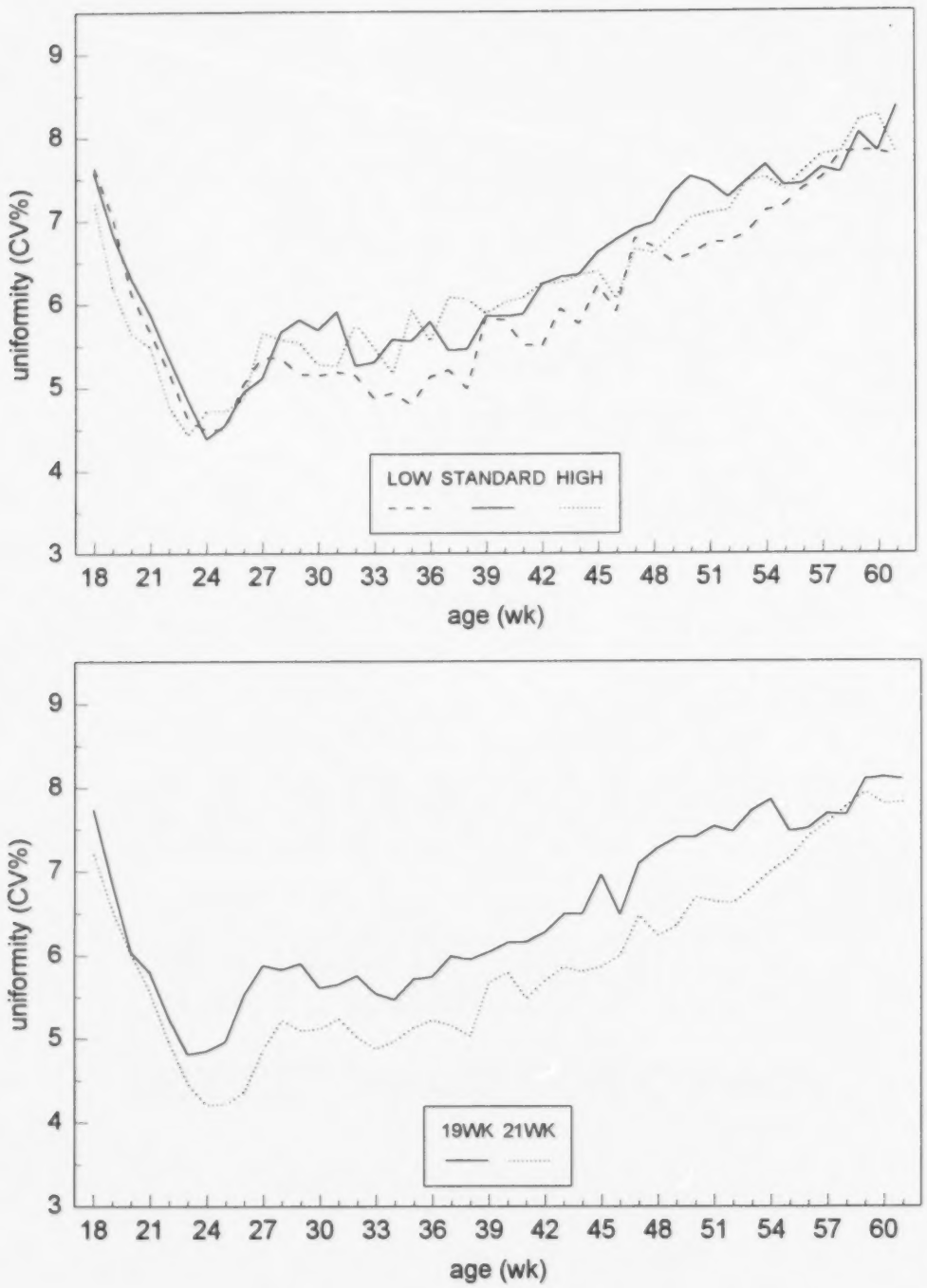

FIGURE 5-3. Upper panel: Weekly uniformity of BW for the main effect of growth curve (LOW, STANDARD or HIGH) from 18 to 61 wk of age. Lower panel: Weekly uniformity of BW for the main effect of photostimulation age (19WK or 21WK) from 18 to 61 wk of age.

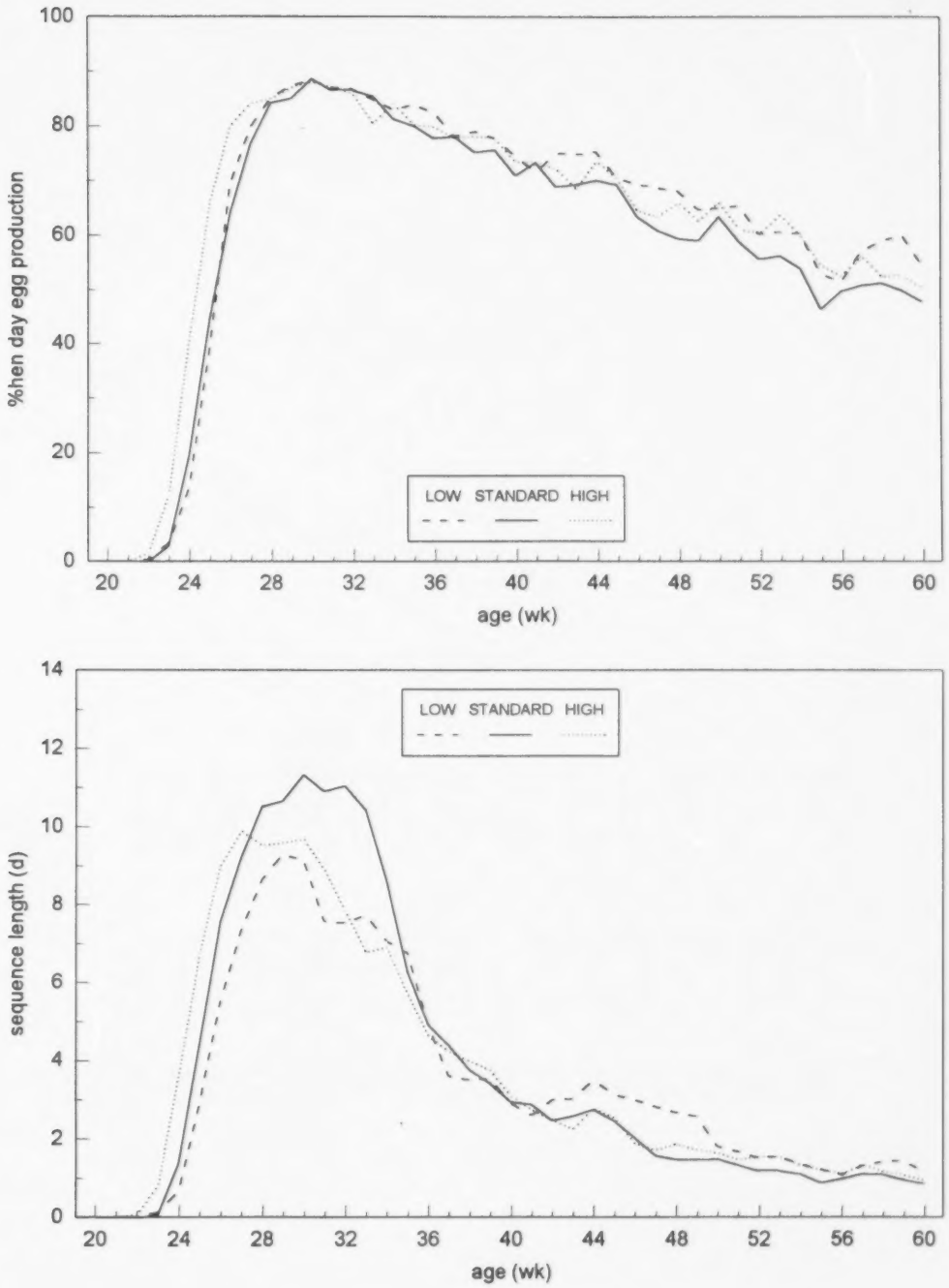

FIGURE 5-4. Upper panel: Weekly hen day egg production for the main effect of growth curve (LOW, STANDARD or HIGH). Lower panel: Weekly sequence length for the main effect of growth curve (LOW, STANDARD or HIGH).

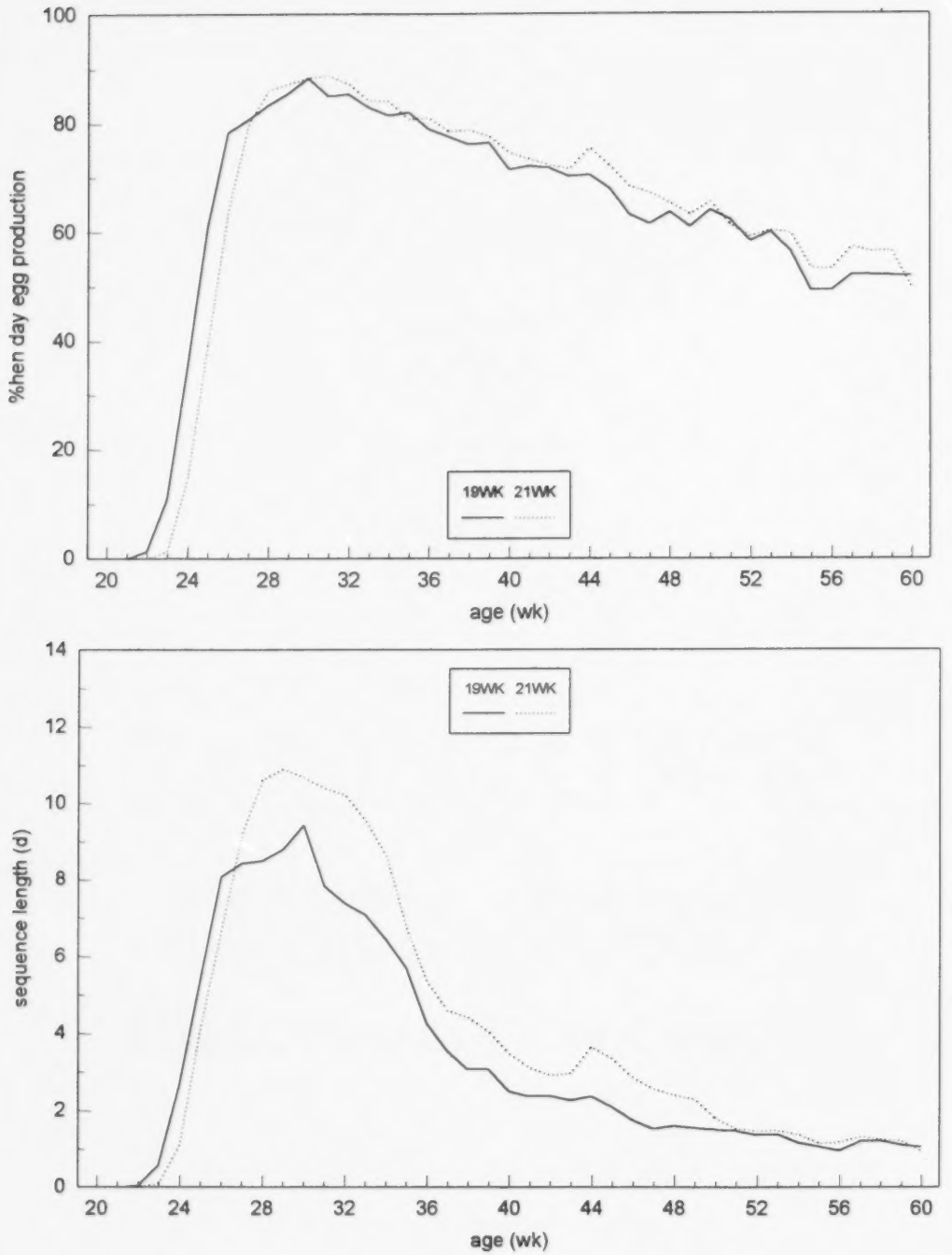

FIGURE 5-5. Upper panel: Weekly hen day egg production for the main effect of photostimulation age (19WK or 21WK). Lower panel: Weekly sequence length for the main effect of photostimulation age (19WK or 21WK).

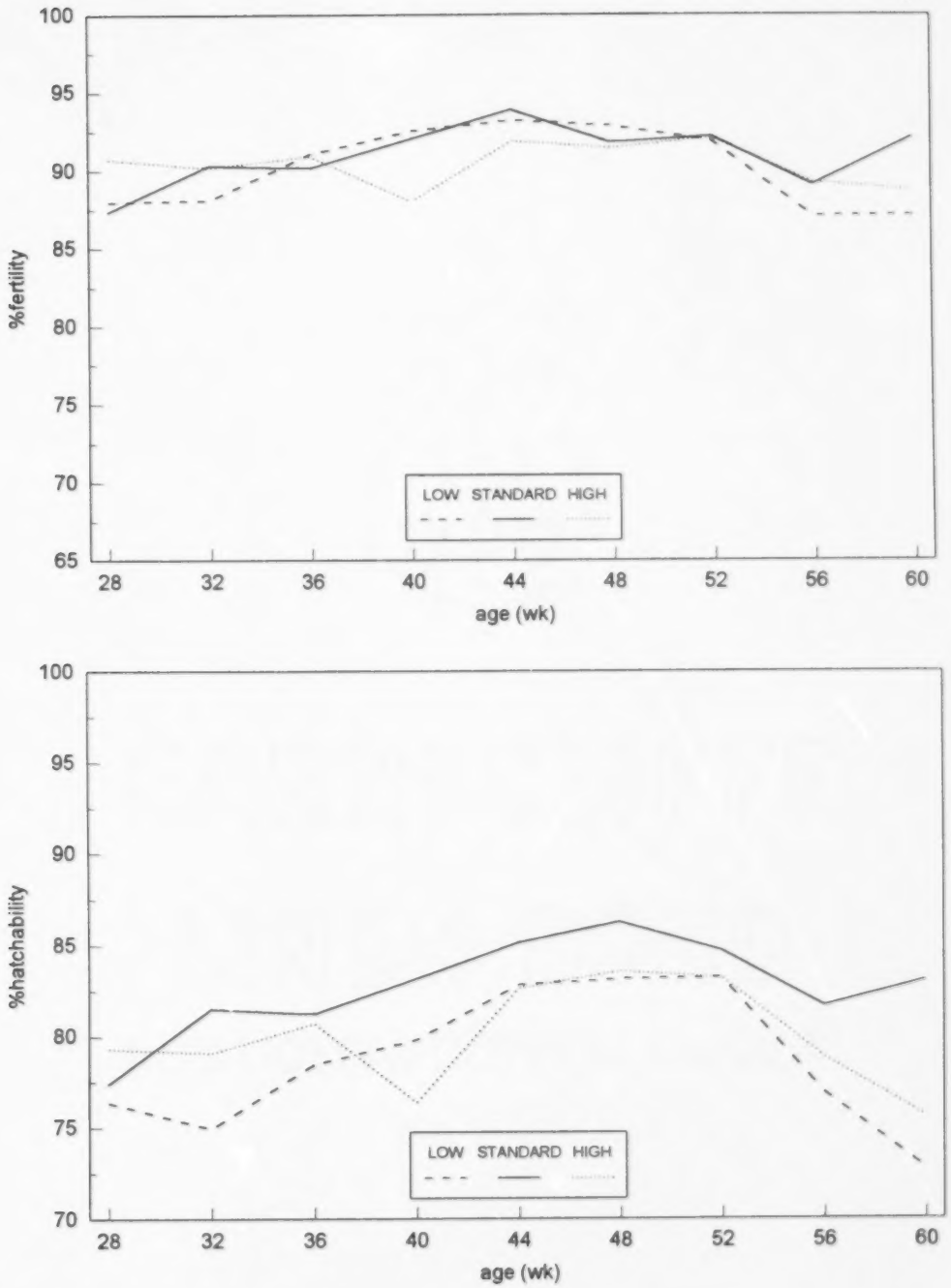

FIGURE 5-6. Upper panel: Monthly percent fertility for the main effect of growth curve (LOW, STANDARD or HIGH). Lower panel: Monthly percent hatchability for the main effect of growth curve (LOW, STANDARD or HIGH).

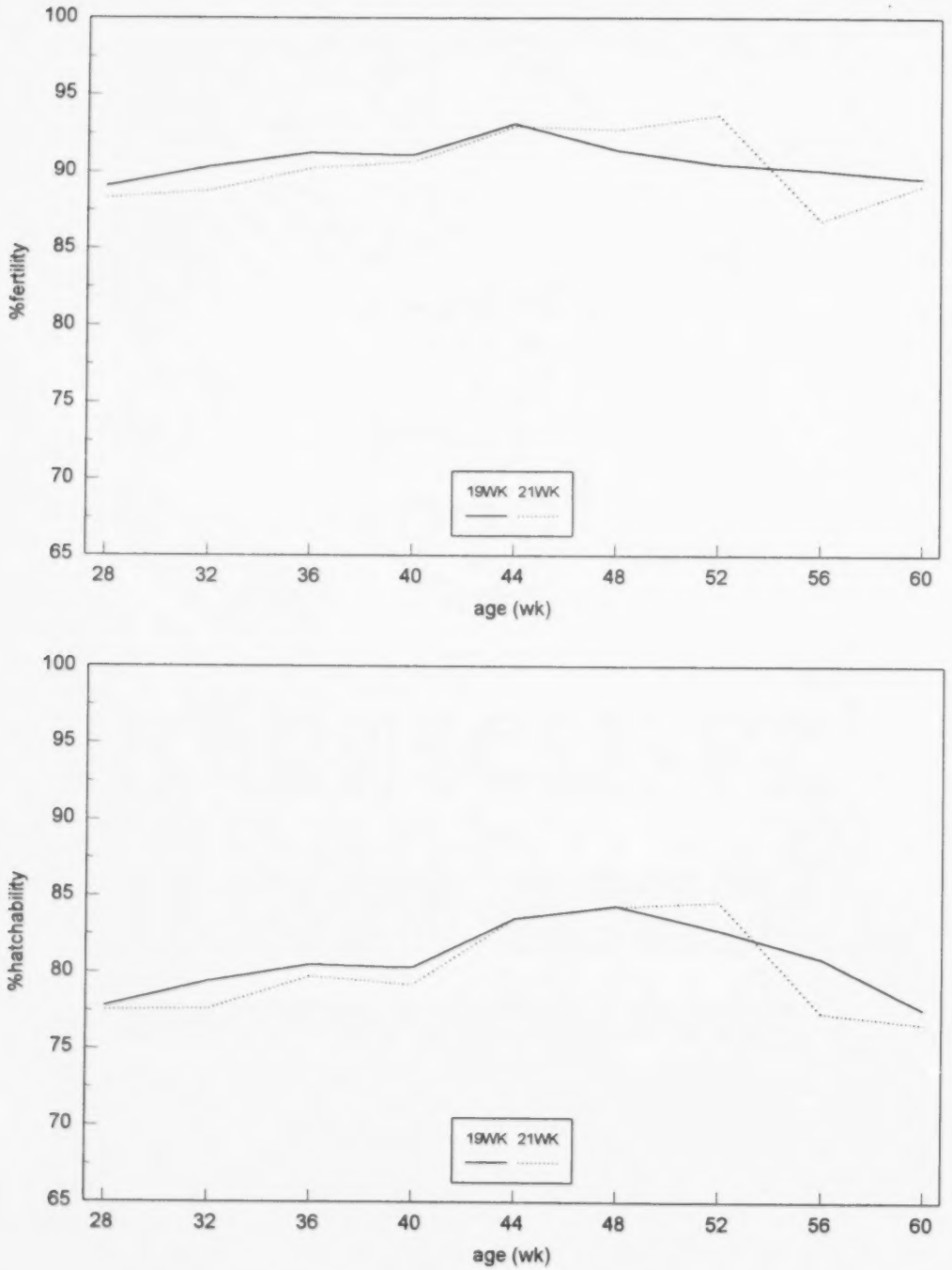

FIGURE 5-7. Upper panel: Monthly percent fertility for the main effect of photostimulation age (19WK or 21WK). Lower panel: Monthly percent hatchability for the main effect of photostimulation age (19WK or 21WK).

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6. GENERAL DISCUSSION AND CONCLUSIONS

6.1 INTRODUCTION

The reproductive performance of the modern broiler breeder hen is considered poor compared to that of the SCWL hen. Yet, the ability of the broiler breeder hen to produce 180 eggs and 140 viable chicks to 61 wk of age, each with the potential to grow to 2 kg within 42 d, is remarkable. This selection for desirable growth and carcass characteristics in the progeny has severely inhibited the reproductive potential of the parent stock (Siegel and Dunnington, 1985). Detailed BW management has become key to ensuring adequate reproductive performance (Robinson *et al.*, 1993). In recent years some primary breeders have lowered BW targets and have delayed the recommended age at photostimulation in order to improve reproductive performance. It was important to determine the effects of these trends using a modern broiler breeder female. This research was inspired by two main objectives. The first objective was to evaluate the effect of *ad-libitum* feeding late in lay on the hen's ability to maintain fertility in the absence of insemination. The second objective was to determine the effect of small differences in growth curve and age at photostimulation, similar to those presently used in the poultry industry, on carcass traits, ovarian morphology and reproductive performance.

6.2 GENERAL DISCUSSION

There has not been a lot of research involving the effect of BW on the duration of fertility. It is generally accepted that there is a negative correlation between duration of fertility and BW in broiler breeder hens (McDaniel *et al.*, 1981; Bilgili and Renden, 1985) and a positive correlation between duration of fertility and laying rate (Beaumont *et al.*, 1992). However, until now no one has compared the duration of fertility between *ad-libitum* and feed restricted broiler breeder hens (Chapter 2). In addition, a definition of the variable 'duration of fertility' was established. Hens that were allowed *ad-libitum* access to feed from 52 to 64 wk of age had a reduced duration of fertility from 60 to 64 wk of age. The effects of *ad-*

libitum feeding on the duration of fertility may be more pronounced with increased time of *ad-libitum* feeding and associated weight gain.

In broiler breeder laying trials at the University of Alberta's Poultry Research Centre, weekly artificial insemination is common practice among different BW treatments. In addition, some primary breeders utilize cage systems and artificial insemination for their pedigree stock, some of which have been reared on *ad-libitum* feeding. These data suggest that weekly artificial insemination is sufficient in order to ensure high rates of fertility in feed restricted and in *ad-libitum* fed broiler breeders. However, if the reduced duration of fertility in the *ad-libitum* fed hens was due to a reduced ability to store sperm, this could affect the likelihood of fertilization regardless of insemination frequency.

It is unknown if the negative effect of BW on the duration of fertility is acting through impairment of sperm selection, storage or transportation. The positive correlation between laying rate and duration of fertility may in fact be two completely independent effects both negatively affected by BW. Duration of fertility and laying rate are both known to be negatively affected by BW. Future studies on the duration of fertility need to address the effect of *ad-libitum* feeding on the factors affecting the hens ability to select, store, and transport sperm.

The trends in recommended BW targets among the primary breeders inspired the majority of this work. Achieving small differences in BW targets requires accurate weighing procedures. Feed allocations are only as accurate as the BW measurements that they are based on. Fattori *et al.* (1992) found time of weighing within one day to be an important source of variation when weighing pullets. However, some producers, researchers or primary breeders may be comparing weights taken on different days of a skipped day feed restriction program. Results presented in Chapter 3 stress the importance of weighing broiler breeder pullets at the same time of the day, on the same type of day each week. Pullet growth curves are generally considered to be smooth. In Chapter 3 they were shown to vary significantly both within one day and between non-feed and feed days. Daily BW targets should be used instead of weekly BW targets in order to ensure appropriate feed allocation. The heaviest and the lightest birds within a flock responded to different weighing times in a similar manner as the entire flock. This is an important consideration for poultry researchers and primary breeders both who routinely select birds based on BW. The effects of

different weighing times during different stages of rearing and breeding need to be examined. In doing so, the importance of weighing time throughout the life of a flock could be determined.

There has been very little research evaluating the effects of small changes in growth curve and age at photostimulation in modern broiler breeder hens. Yuan *et al.* (1994) asked the question; "can heavy rearing BW and early photostimulation improve reproductive and economic performance?" They were unable to provide an answer. Fattori *et al.* (1991, 1993) demonstrated that greater restriction of BW could reduce feeding costs without adversely affecting reproductive performance. Wautier (1994) determined that earlier photostimulation negatively affected the pullets ability to respond to the photostimulatory cue and negatively affected chick production. However, neither of these trials investigated the interaction between BW and age at photostimulation. The present experiment asks a similar question to the one asked by Yuan *et al.* (1994). Here, I used growth curves and ages at photostimulation similar to those used in the poultry industry. I was also interested in characterising the onset of sexual maturity and determining if the recommended BW targets were appropriate. Broiler breeder management guides are becomingly increasingly fine tuned and it is necessary to determine the effect of small differences in the level of feed restriction and the age at photostimulation on performance of modern broiler breeders.

The heavier weight birds possessed similar carcass traits at 19 wk of age to those of the lighter weight birds at 21 wk of age. Yet, egg production data did not support advancing age at photostimulation for heavier weight birds. Earlier photostimulation required earlier increases in feed allocation, resulted in a longer time in egg production, and did not increase any measure of reproductive performance. I recommend against early photostimulation for pullets within the range of BW used here. In fact, there may be some advantage to delaying age at photostimulation even later. The birds photostimulated at 21 wk of age showed trends of being more uniform in BW at sexual maturity, age at sexual maturity, and age at a settable egg. These trends may have been significant with larger delays in the age at photostimulation. These results suggest that delaying the age at photostimulation may reduce management difficulties associated with modern broiler breeders by improving uniformity characteristics. If birds photostimulated later had greater rates of lay late in the laying cycle, duration of fertility may be greater as well. Birds producing at higher rates of lay would have longer egg laying sequences, would presumably have better

control over their ovulatory cycle and may produce fewer defective and double yolked eggs. Management techniques that reduce the negative effect of selection for growth on reproductive function need to be examined in more detail.

Feed restriction is necessary to control BW (Yu *et al.*, 1992a) and ovarian follicular development (Hocking *et al.*, 1989; Yu *et al.*, 1992b) in order to ensure adequate reproductive function (Robinson *et al.*, 1993). Only one report exists describing relatively minor feeding differences affecting large follicle recruitment in broiler breeders (Robinson *et al.*, 1995). In that report, one additional LYF at sexual maturity was associated with a reduction of ten eggs over the laying cycle. There is a negative impact of increased follicular recruitment at sexual maturity on subsequent reproductive performance (Hocking *et al.*, 1989). Therefore, the effect of small differences in growth curve on ovarian morphology at sexual maturity needed to be evaluated. The modern broiler breeder was shown to be very sensitive to small differences in feed allocation. The increased follicular development at sexual maturity in the B-Group HIGH birds was associated wih the production of more double yolked eggs by the C-Group HIGH birds. It is likely that F2 follicles showed functional similarities to F1 follicles (Yu *et al.*, 1992c), a phenomenon characteristic of erratic ovulation defective egg syndrome (EODES). Correlations between defective egg production, hatchability, BW, total eggs, and the percent of LYF within 1 g also suggested that a mild condition of EODES was evident in the heavier weight birds. In the past this syndrome has been reserved for *ad-libitum* fed broiler breeder hens (Robinson *et al.*, 1993). The sensitivity of the broiler breeder hen to differences in growth rate justifies the importance that primary breeders place on small differences in BW target. However, cautioning against slightly higher growth rates may be premature. The HIGH birds produced similar numbers of eggs and chicks, and double-yolked egg production was very small. The logical next step in relating follicular development, growth curve and reproductive performance may be to process birds at intervals of one week from the time of photostimulation through to the end of lay. In doing so a profile of BW, follicular recruitment, and laying patterns could be generated on an individual hen basis. The impact of the number of LYF on egg production throughout the laying cycle could then be determined.

Thresholds of carcass composition, chronological age, and BW necessary for the onset of lay have

been studied and proposed using older strains of broiler breeders and White Rock females. However, details of thresholds required for the onset of lay in modern broiler breeders have not been intensively investigated. In Chapter 4, a two level threshold of carcass composition and ovarian morphology necessary for the onset of sexual maturity was proposed. The ability of the bird to respond to the photostimulatory cue may be dependent on achieving thresholds of carcass composition necessary for maturation and function of the hypothalamic-anterior pituitary axis. Maturation of this axis and the associated production of GnRH and LH are responsible for stimulation of the ovarian hierarchy to a threshold necessary for sexual maturity. The increased rate of estradiol-17β production by the birds photostimulated at 21 wk of age may reflect their advanced stage of maturity at the time of photostimulation. Measurement of the plasma estradiol-17β concentration may be an excellent indicator of the birds ability to respond to the photostimulatory cue. In future studies, plasma estradiol-17β concentration should be measured at least 2 wk prior to photostimulation and bi-weekly through to the time of sexual maturity. Profiles of estradiol-17β levels would indicate the birds ability to respond to the photostimulatory cue and could be correlated to carcass traits and ovarian morphology at similar intervals of time.

The effect of small differences in growth curve on reproductive performance has previously been investigated by Fattori *et al.* (1991). They demonstrated an increased persistency of lay with higher levels of feed restriction. In the present trial, the STANDARD birds (Chapter 5) had lower total egg production, lower soft shelled egg production, and higher levels of hatchability of settable eggs and of fertile eggs set. While possible causes of this significant difference in reproductive performance were investigated, it's cause remains undetermined.

Generally, it is accepted that broiler breeders have an excess of LYF early in lay that inhibits normal ovarian function and egg production (Hocking *et al.*, 1989; Yu *et al.*, 1992b). It is also generally accepted that reductions in the rate of lay are due in part to reductions in follicular recruitment and number of LYF late in lay limits egg production (Bahr and Palmer, 1992). Supposedly, at some time during the laying cycle the ovary has an optimal number of LYF necessary for high rates of lay. This stage in the laying cycle most likely occurs at the time of the prime sequence. Prime sequence length was positively correlated to total egg production, supporting work of others (Robinson *et al.*, 1990). The results clearly

showed that birds producing more total eggs, had more LYF, and were lighter in BW at the end of lay than birds producing fewer total eggs. The same was true of birds with longer prime sequences. If the mechanism responsible for follicular recruitment could be identified, then management programs could be geared at controlling it. Current management programs limit follicular recruitment through limiting BW at sexual maturity. Currently, LYF numbers at sexual maturity are controlled by managing BW. However, while BW and LYF numbers are positively related at sexual maturity, they are negatively related late in lay. Body weight is likely not the main factor affecting LYF numbers throughout the life of a broiler breeder. Ideally, management techniques could be aimed at the mechanisms underlying the follicular recruitment process. However, these mechanisms have yet to be determined.

6.3 CONCLUSIONS

These data suggest that small differences in growth curve have an effect on reproductive performance. Birds grown on slightly higher growth curves showed mild symptoms of EODES. Although, the effect was small, and did not justify the use of only lower weight growth curves, it serves to characterize the sensitivity of the reproductive performance of the modern broiler breeder to small differences in feed allocation. This should act as a warning to the breeding industry. Advancing age at photostimulation, even when carcass traits favour it, is not advised within the range of BW used here. By delaying age at photostimulation, reproductive function late in lay was improved. This improvement in the reproductive performance suggests a higher level of control of follicular recruitment and maturation, leading to a more efficient ovulatory cycle. The incidence of EODES may be minimized by providing management techniques that ensure normal reproductive function. Later photostimulation and lighter growth curves may be two ways of making the modern broiler breeder hen act more like a SCWL hen.

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